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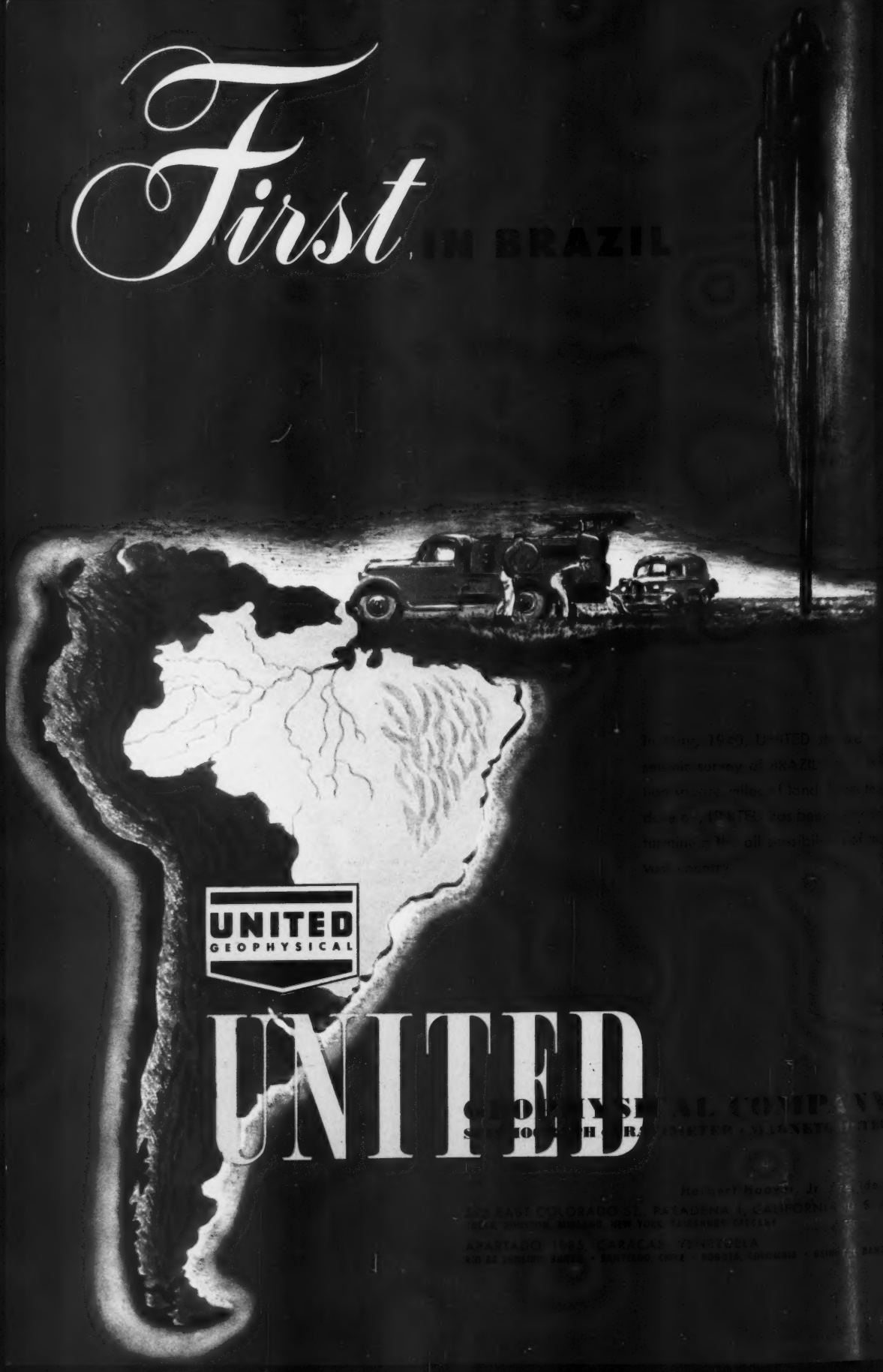

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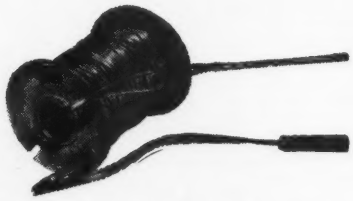

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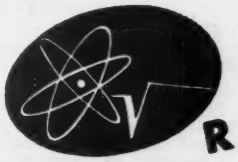

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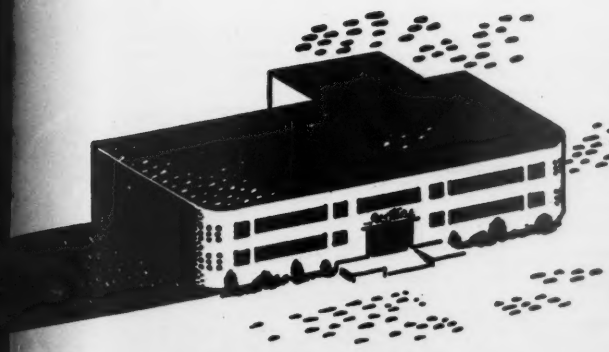

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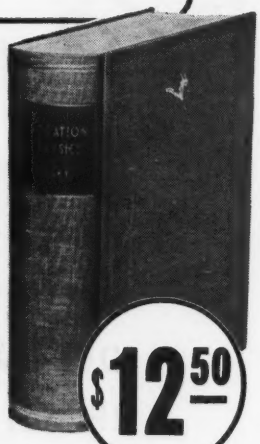

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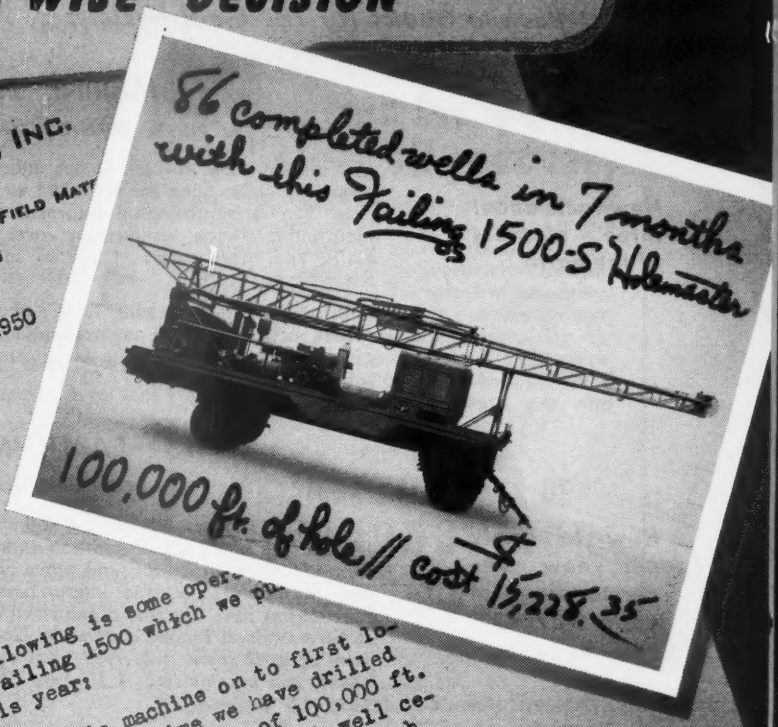

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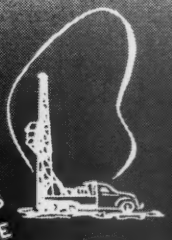

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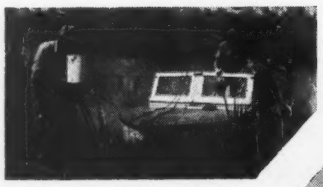

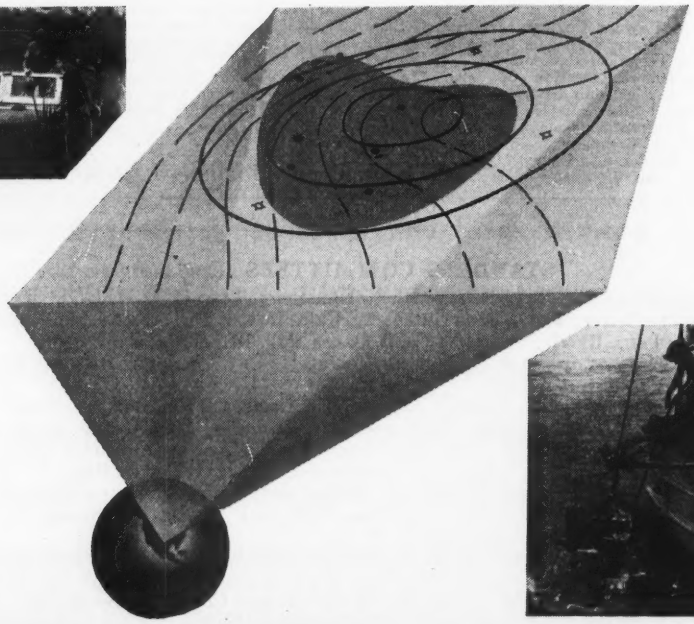

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GEOPHYSICS

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GEOLOGY AND GEOPHYSICS OF THE NORTH SNYDER AREA, SCURRY COUNTY, TEXAS*

NEAL CLAYTON†

ABSTRACT

Discovery of the North Snyder reef in November, 1948 by the Standard of Texas focused the attention of the oil industry on this part of West Texas and presented the geophysicist with the problem of how to locate other reefs of this type.

The North Snyder reef is unique in that reflected energy is obtained from the reef-shale contact in some parts of the field. Magnetic, gravimetric and seismic data are presented to show some of the effects to be expected from a reef of this type.

A number of electric log correlations are included in order to illustrate the geology of the field. From the electric logs it appears that the "draping" effect is small above the thick Pennsylvanian shale section which compensates for the reef mass. Contour maps for the base of the Coleman Junction limestone and the top of the Canyon reef are presented.

INTRODUCTION

The discovery of the North Snyder reef in November, 1948, by the Standard of Texas No. 2–1 Brown focused the attention of the entire oil industry on this part of West Texas and at the same time initiated the greatest lease and royalty play since East Texas. This particular field is important for several reasons. In the first place, the discovery took place in what had previously been considered a "no man's land" for oil men. The phrase, "stay out of Scurry County," has since proved to be very embarrassing to many geologists. Secondly, seismic record quality is such in the area that had a reconnaissance type survey alone been used, the prospects would most certainly have been classified as marginal. It was only by the use of close detail that sufficient data were obtained to justify use of the drill. North Snyder is important because it is an example of a Pennsylvanian reef located directly by means of reflected energy obtained from the reef itself. Most other reef discoveries, at least in West Texas, have resulted from indirect seismic methods, e.g., the mapping of beds affected by the reef mass, and last, but not least, the field is important to geophysicists because it represents a geophysical discovery.

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† Republic Exploration Company, Tulsa, Oklahoma.

Location of the discovery well was based on a reflection seismograph survey made for the Standard Oil Company of Texas by the Southern Geophysical Company. The North Snyder area is located in the west central part of Scurry County, some eight miles north of the town of Snyder, Texas, from which it gets its name. (See Fig. 1.) The field divisions shown are merely arbitrary ones. Re-

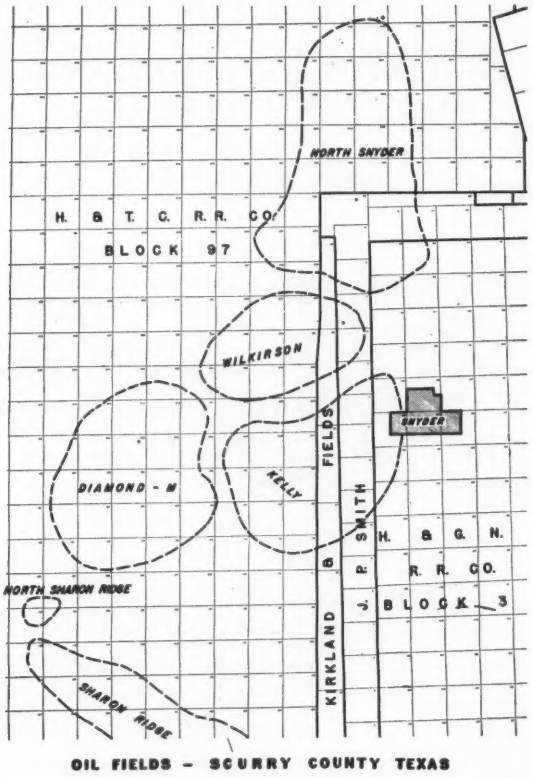

FIG. 1. Location of the North Snyder reef area with respect to other major fields in Scurry County.

cently the Kelly, Snyder, and Wilkirson reefs have been declared a common reservoir. It is now an established fact that this field is merely one of an arc or chain of Canyon reefs extending from Terry County to Kent County. North Snyder thus far is the largest of the fields in this chain.

HISTORY OF DISCOVERY

Early Exploration: During the late nineteen thirties and early nineteen forties, many oil companies conducted reconnaissance type surveys with the magnetometer or gravity meter in Scurry County. These included the Humble, Magnolia, Standard of Texas, Gulf, Ohio, General Crude, American Republics, Mid-

Continent, and others. It is reported that at least one of the gravity surveys indicated a pronounced maximum at North Snyder upon which a sizeable block of acreage was taken, but later dropped. A magnetometer map of the area prepared before the reef development began indicates an east-west trend from a pronounced anomaly some three or four miles to the east. (See Fig. 2.) This

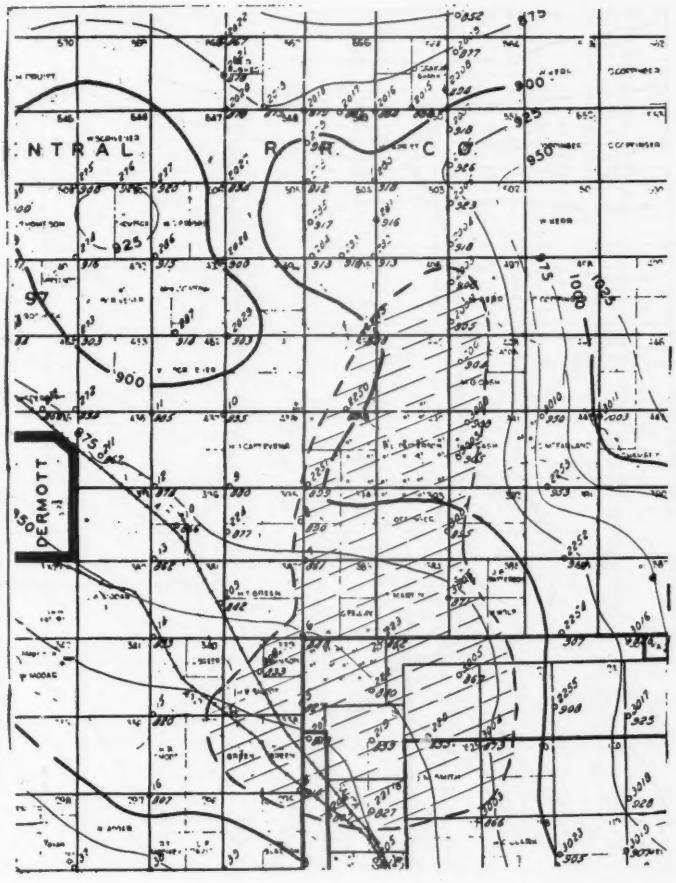

FIG. 2. Magnetic map of the area immediately surrounding the North Snyder reef. Contour interval—25 gammas.

strong anomaly will be discussed subsequently in more detail. A broad anomaly is indicated northwest of the field in an area of scattered Ellenburger production. Several positive Ellenburger areas are located in this general direction. Although the station density used in the vicinity of the North Snyder reef is small, no definite anomaly seems to be present there. A contour interval of 25 gammas was used in the preparation of his map.

A total gravity map of this part of Scurry County prepared in the early part

of 1944 by the Magnolia Petroleum Company indicated no outstanding anomaly associated with the reef. (See Fig. 3.) The strike of the regional contours here is due primarily to the large Crosbyton maximum to the northwest. Although there is apparently no subsurface expression for this anomaly, at least above the granite, it is not entirely beyond the realm of possibility that perhaps some feature

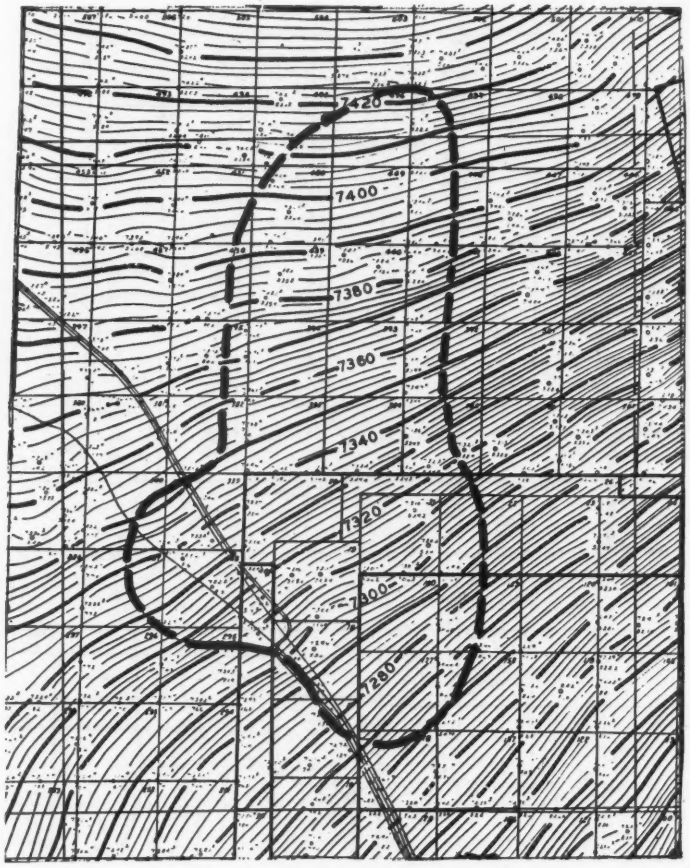

FIG. 3. A total gravity map of the North Snyder reef area, courtesy of the Magnolia Petroleum Company. Contour interval—0.2 milligal.

in this area during the past geologic time initiated the great arcuate pattern of reefs currently being developed. A contour interval of 0.2 milligal and a surface density factor of 0.68 units per foot were used in the preparation of this map.

A second order gradient map prepared from the total gravity by Republic's gravity department shows a long north-south maximum, most pronounced in Section 440 where the discovery will was drilled. (See Fig. 4.) This feature is surrounded by a "halo" or ring minimum. This latter effect would be increased by

a reduction in the value of the density factor. A northeast-southwest trend is apparent. Over the Wilkirson reef to the southwest a minimum is present. This could possibly be explained by a net decrease in the amount of shale above the reef in this direction. Several electric log cross sections will be used later to illustrate this possibility.

Seismic Exploration: The Humble Oil and Refining Company worked the

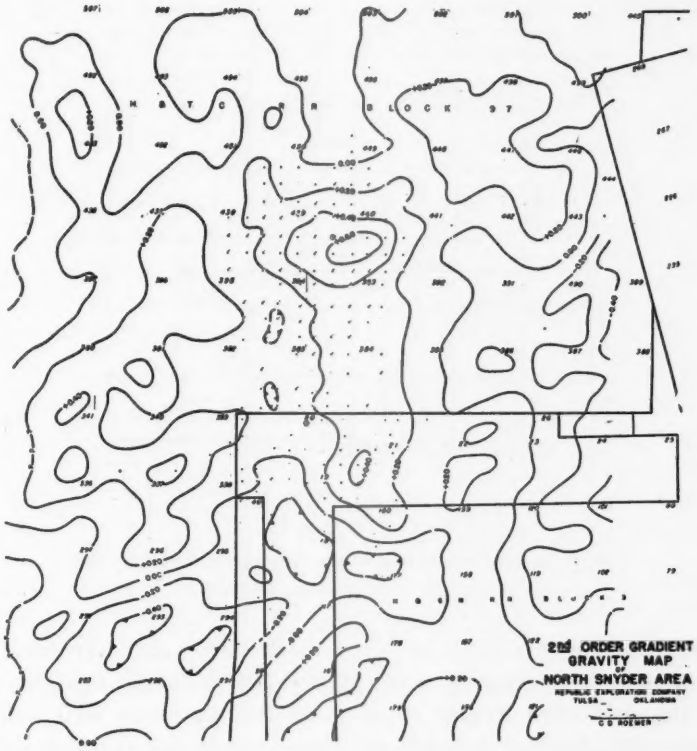

FIG. 4. A second order gradient map prepared from Figure 3.
Contour interval—0.2 milligal.

North Snyder area in a reconnaissance fashion with the reflection seismograph for a few months in 1938. A program of correlation shooting was followed. Some acreage was taken as a result of the survey. It is reported that a northwest-southeast trending feature extending through Section 339 was indicated by this survey. Later, in the early summer of 1946, two months of continuous profile shooting was done in the area. As a result of this later work, the Humble drilled their No. 1 Davis in the SW SW of Section 339, H & T C RR, Block 97. This well topped the Canyon reef at −4,312, but was abandoned as a dry hole in January of 1947 without testing the reef. The well was drilled as an Ellenburger test,

however, and at that time the thick Pennsylvanian lime section was not recognized as reef material.

The Standard Oil Company of Texas in 1944 had acquired a block of acreage several miles to the east of the North Snyder reef as one of a number of leaseholds resulting from gravity and magnetometer studies in West Texas. This particular block was located on a magnetometer anomaly, the same strong feature pointed out previously on a magnetic map of the area. A Southern Geophysical Company

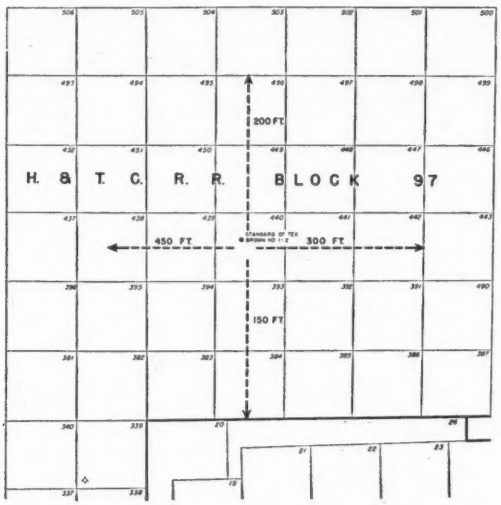

FIG. 5. Amount and extent of the structure revealed by the Standard of Texas seismic survey.

crew began detailing this block in September, 1947. Later, the survey was extended to include the north part of the present North Snyder field. Shooting continued in the area until August, 1948 when the discovery well was spudded. Normal reflection shooting methods were used, employing 24 trace seismographs, with two geophones per trace and holes spaced 1,000 to 1,500 feet apart. Ground overlap was not used. However, mixing was employed, in some instances as much as 66%. Record quality was generally poor over much of the area. This is due in part to the presence of caliche or weathered Ogllala at the surface over most of this part of Scurry County. To enhance the reliability of the correlations, a grid of profile lines along east-west and north-south boundaries and diagonal lines through the corners and centers of the six or seven sections centering about Section 440 was used.

Interpretation of this work indicated the presence of a sizeable pre-Permian structure centering in Section 440. Figure 5 indicates the amount and extent of the dips found by the survey. No tie was made to the Humble No. 1 Davis in Section 339, the only deep test in the area at that time. A phantom was carried for

the top of the reef, which explains why the relief indicated by shooting was less than that shown by drilling. A sizeable lease block was taken over the structure revealed by the survey.

Shortly after completion of their discovery well, the Standard of Texas ran a detail gravity survey over an area of 100 square miles surrounding the north part of the North Snyder reef. Sixteen stations per square mile were used in the survey. Interpretation of the data failed to reveal any anomaly associated with the reef mass.

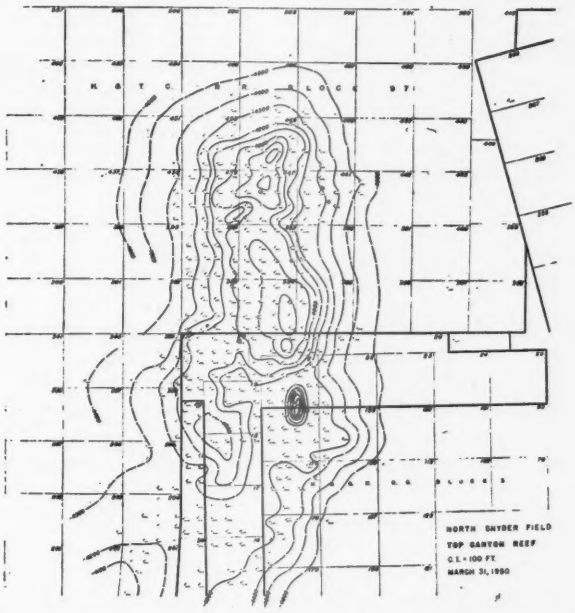

FIG. 6. Contour map of the North Snyder reef based on well control.

A contour map of the top of the reef based on well control indicates the general features of the field (Fig. 6.) The discovery well in the southeast quarter of the northwest quarter of Section 440 was apparently accurately located on the apex of the reef by the shooting. An important extension well, the Sunray, Ryan, Hays & Burke No. 1 Brown, some three miles south, completed in April 1949, was only 200 feet lower than the discovery. Seismic work began by Republic for Sunray following completion of this well predicted that the crest of the reef would be found about one mile to the east. Drilling has since proved this to be the case.

Development of the North Snyder field has provided several exciting lease and royalty plays. Possibly the most spectacular of these was one which followed completion of the Castleman and O'Neill No. 1 Huckabee in the northwest quarter of the northeast quarter of Section 160 during September, 1949. This well topped the reef at −3,750, thus becoming the highest well in the entire area.

Since the well was two miles southeast of the nearest production at that time, it was believed the trend would be in this direction. Later drilling has shown this well to be on a very small peak located on a rather broad terrace.

An east-west seismic time cross section over the south part of the field illustrates some of the problems involved in locating a reef of this type by seismic methods. (See Fig. 7.) Over most of the area energy is reflected from the reef-shale contact. This in itself is unusual for most West Texas reefs. Few continuous events below the reef are obtained, and those from the Permian show little

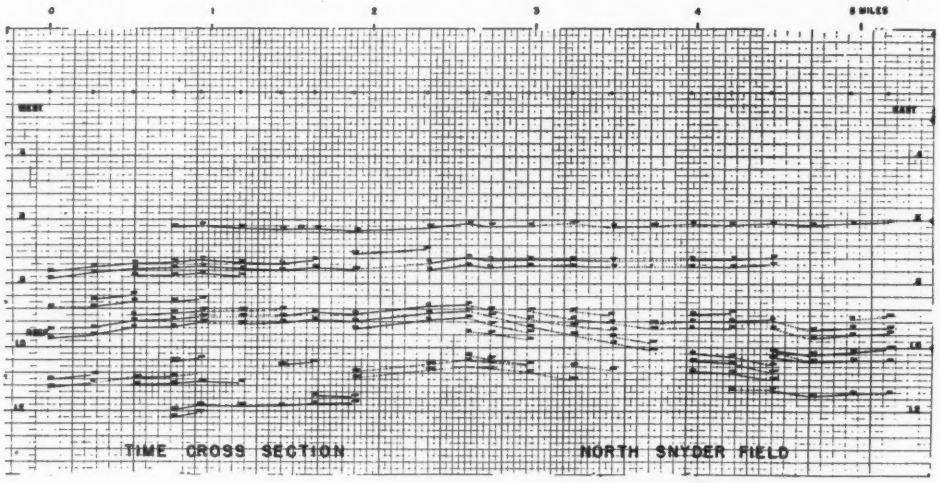

FIG. 7. Seismic time cross section over the North Snyder reef.

or no relief over the reef. For these reasons the usual methods for locating reefs by the seismograph are difficult to apply here. One clue should be noted about the shallow events, however, and that is the steepening of the dip in these beds toward the basin. In order to prepare a Permian map over this reef from shooting, very close control and the use of a phantom would be necessary. The presence of "transient" events in the shale section above the reef is particularly troublesome east of the reef crest.

Figure 8 is an example of how the reef event may be identified in areas where it is good and continuous. Any difference in "step-out" time across the record between the reef event and other events on the record is most important in identifying this reflection beyond breaks in the continuity. In many spots the reef event is discontinuous, making the use of close control imperative. That the reef event is not continuous over the entire area is not too surprising since an examination of the electric logs indicates considerable variation in both porosity and resistivity for the top of the reef. Cores from several wells in the field have shown the reef material to be less dense than the overlying shale.

GEOLOGY

The geology of North Snyder will be illustrated by means of several electric log cross sections. Regionally, the field is located on what is known as the eastern shelf of the Permian Basin. The Permian-Pennsylvanian contact is near the top of the black shale which overlies the reef. The section above −1,800 feet is monotonously regular and so will not be discussed here. A marked change in lithology occurs between the base of the Coleman Junction limestone of lower Permian age and the top of the black shale, even between adjacent well locations. As a rule, the top of the shale section is difficult to correlate without the use of samples. Consequently, most reflections obtained from this part of the section are continu-

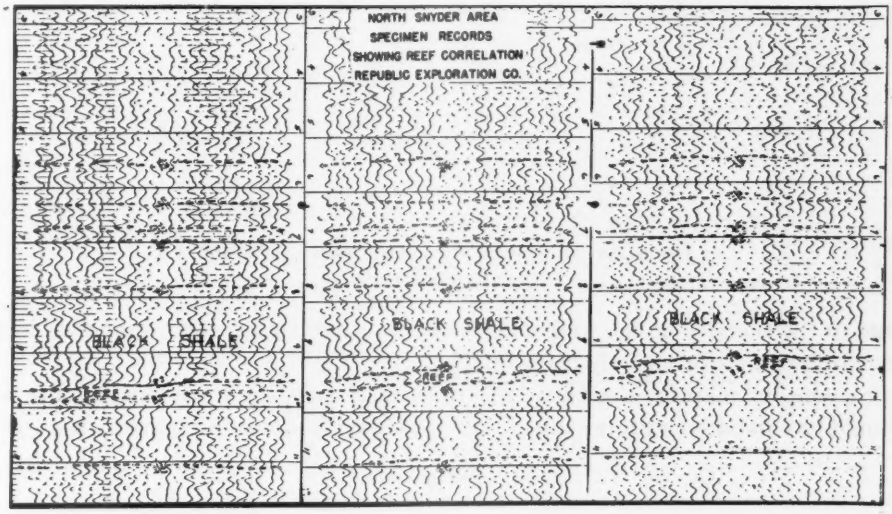

FIG. 8. A sequence of three 1,320-0-1,320 foot records showing positive identifications of the reef event.

ous for only a short distance. In general, this has proved to be the case over most of the North Snyder area.

Figure 9 is an east-west well cross section along a line one location north of the discovery well for the North Snyder field. While there seems to be a very slight amount of reversal in the lower Permian over the reef, most of the compaction or draping appears to be within the shale section. This would appear to be a reasonable assumption since shales as a rule undergo more compaction than do limestones.

The relationship of beds below the reef is illustrated by Figure 10. From this correlation the "reef buildup" appears to begin some 400 feet above the top of the Ellenburger or in the upper Strawn. No pronounced Ellenburger high is indicated below the reef. The Standard No. 2–5 Brown in Section 440 is the only well thus far which has been taken to the Ellenburger on the crest of the reef.

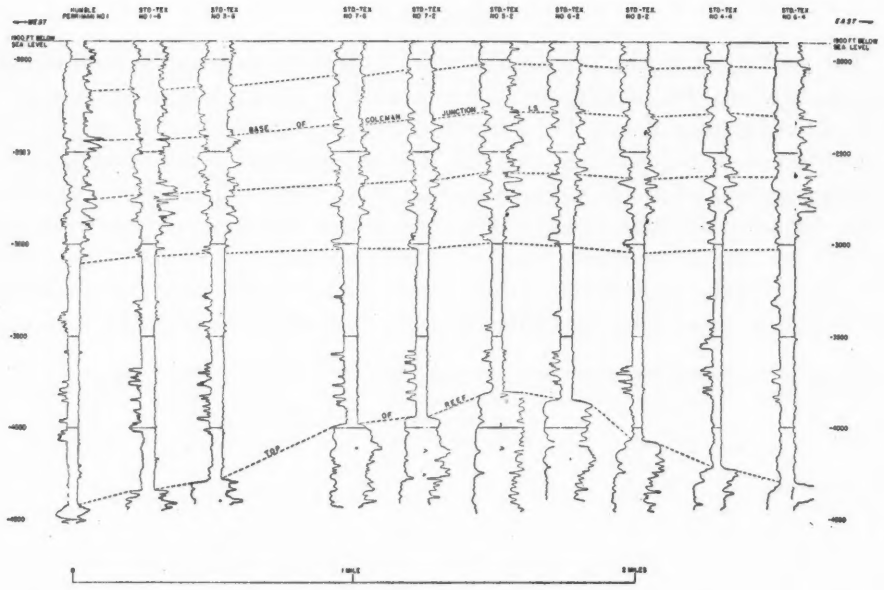

FIG. 9. An east-west electric log correlation across the north part of the reef.

Due to the scarcity of the well control for the Ellenburger, the presence of local structure cannot be entirely discounted.

A contour map for the base of the Coleman Junction limestone, Figure 11, should be compared with the top of the Canyon reef, shown in Figure 6. The Cole-

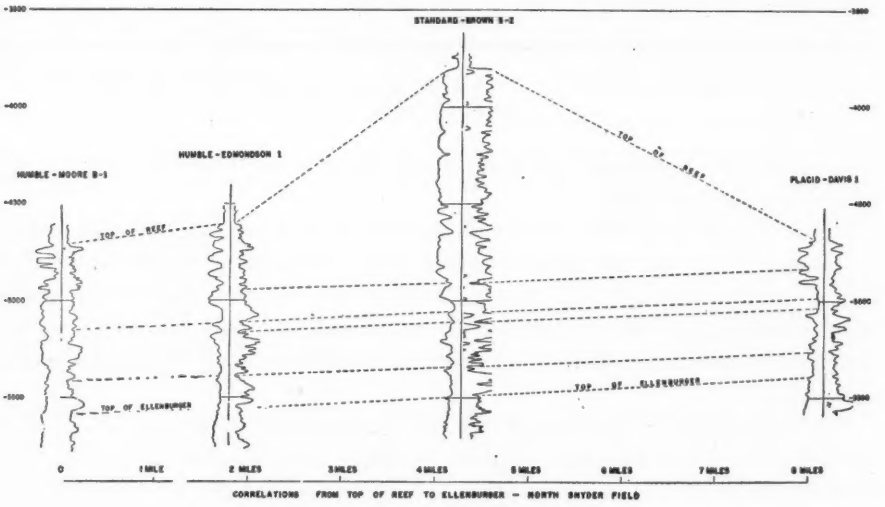

FIG. 10. An east-west electric log correlation showing the relationship of the reef to the underlying formations.

man Junction shows a small amount of closure over the crest of the reef, an increase in regional dip to the west, and a decided flattening to the east of the field. Closure is present around the sharp peak in Section 160 and to the northwest in the direction of Section 339. It is believed this trend through Section 339 is a line of Post-Pennsylvanian folding unrelated to the reef mass. Perhaps the presence of a gravity minimum over the Wilkirson reef is due to the net loss of

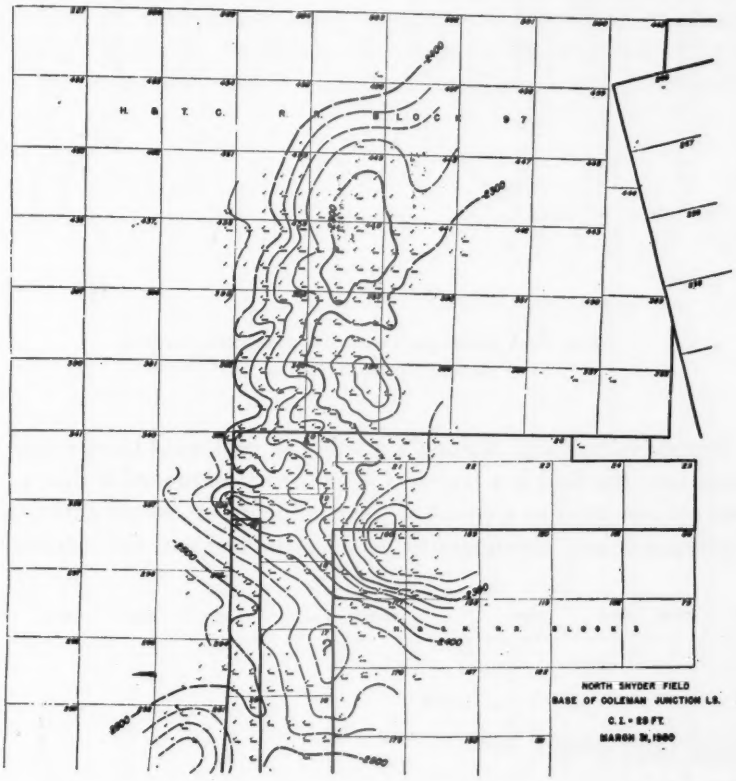

FIG. 11. Contour map of the base of the Coleman Junction limestone over the North Snyder reef based on well control.

shale between the Coleman Junction and the reef. The difficulty of attempting to correlate stringers within the black shale should be apparent from this cross section. The presence of local reefing within the lower Permian should be noted.

Figure 13 is an east-west cross section one location north of the high Castleman and O'Neill well. It indicates convergence to the west between the Coleman Junction and the reef. This cross section is similar to the previous one, except for the absence of a shale member immediately below the Coleman Junction. Again the occurrence of local reefing in the lower Permian is noticed.

North Snyder thus far in this paper has been referred to as a Canyon reef of

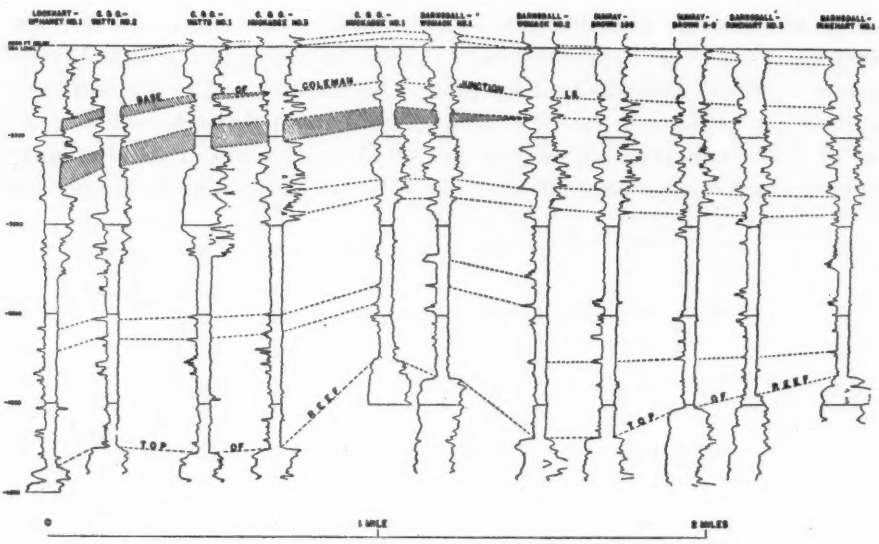

FIG. 12. A north-south electric log correlation across the sharp peak in Section 160.

middle Pennsylvanian age. Among a number of geologists there exists considerable doubt that the field is a true reef. One theory advanced is that perhaps the limestone accumulated as a result of the confluence of certain currents. The apparent absence of any interfingering between the reef and the surrounding shale

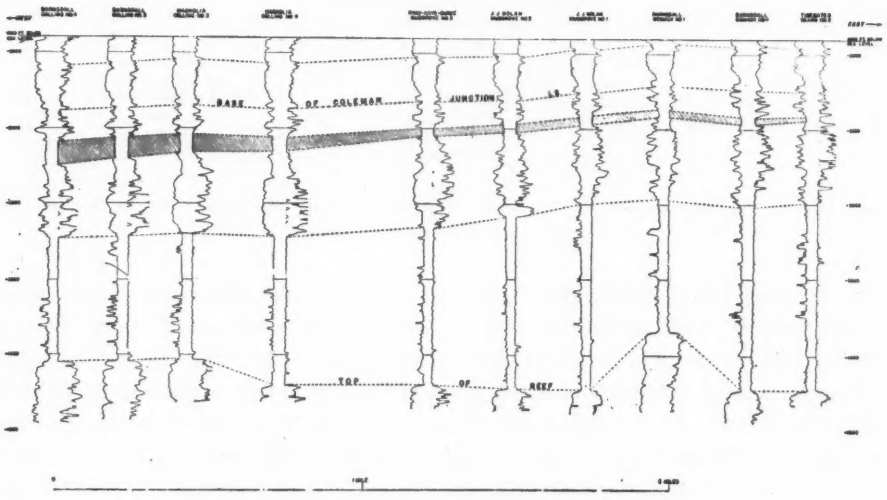

FIG. 13. An east-west electric log correlation across the south part of the reef.

is offered as evidence of such a theory. Apparent stratification within the reef as indicated by electric logs also seems to refute the reef theory. At least it can be said that this Scurry County field has revised the thinking of many geologists and geophysicists regarding reefs.

In closing, the author would like to thank the following companies whose cooperation made the preparation of this paper possible: The Standard Oil Company of Texas, The Magnolia Petroleum Company, The Barnsdall Oil Company, The Deep Rock Oil Corporation, and the Sunray Oil Corporation. In addition he would like to thank the geologists and geophysicists with whom he has discussed this particular field. Some of their theories and comments are included in this paper.

CASE HISTORY OF BENTON FIELD, BOSSIER PARISH, LOUISIANA*

C. N. VALERIUS† AND STEFAN VON CROY‡

ABSTRACT

A regional gravity-meter survey executed during the summer of 1943 along the eastern slopes of the Sabine uplift indicated the presence of a prominent minimum trend. The first traverse of a subsequent reflection seismograph survey in portions of Townships 20 and 21 north, Ranges 12 and 13 west, Bossier Parish, Louisiana, revealed strong critical west and north dips, after which the Benton structure was delineated by a moderate amount of seismograph work. Geophysical maps of the raw gravity configurations and two seismic control horizons are presented. A comparison of the base of the anhydrite control with the deeper seismograph horizon, later identified to be somewhat below the Bodcaw sand of the Cotton Valley series, demonstrates the shifting of the structural axes down dip with increased depth.

The discovery well on the apex of the structure and 16 other development wells confirm the outline of the seismic Cotton Valley picture. The structure is an elongate anticline approximately seven miles long with an average width of two and one-quarter miles. Although only 60 feet of closure on the "D" sand has been proven by drilled wells, it is evident that total closure must exceed 100 feet. The history of folding of the Benton structure reveals interesting comparison of the results of the local causative forces as opposed to the effects of regional tilting due to the Sabine uplift. The remarkable accuracy of the seismic data was chiefly responsible for the unusual development following discovery of the field which resulted in early unitization of leaseholds which later included mineral and royalty interests. This permitted very economical drilling costs and proper spacing and location of wells to secure efficient drainage.

GEOPHYSICAL DATA AND MAPS

The case history of the Benton Field is a very good example of how teamwork between geologists and geophysicists can result in the smooth execution of an exploration program in an area which, because of insufficient information, was presupposed to be devoid of worthwhile structures. Figure 1 shows the location of the Benton Field with reference to prominent landmarks. The area covered by the immediate structure is, of course, only a small part of the territory which was originally selected for geophysical investigation. For obvious reasons, only the maps of the structure and its immediate surroundings are presented in this paper.

In general, the survey area can be described briefly as a broad, well-dissected ridge trending northeast-southwest, sloping eastward to the Bodcaw creek bottoms and west and southwestward to the Red River. The elevations range from 180 to 330 feet. The area is heavily timbered, and the surface is composed of recent alluvial deposits, Pleistocene gravels, and Eocene clays and shales. The soft varied colored clays and shales of the surface formations alternate with irregular layers of sand and gravel, passing into a coarse black shale within shot hole depth. This black shale was found to be the most consistent near-surface formation, and whenever possible, shot holes were bottomed in it.

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During the spring and summer of 1943, a regional gravity meter survey in the general area of the eastern slopes of the Sabine uplift revealed a hoped for, but rather surprisingly prominent, minimum trend in an otherwise relatively un-

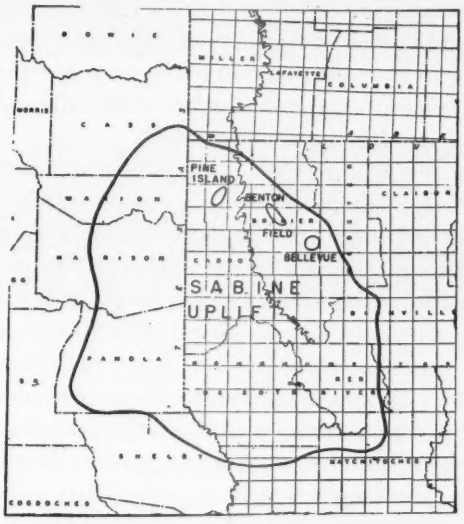

FIG. 1. The location of the Benton Field with reference to prominent landmarks.

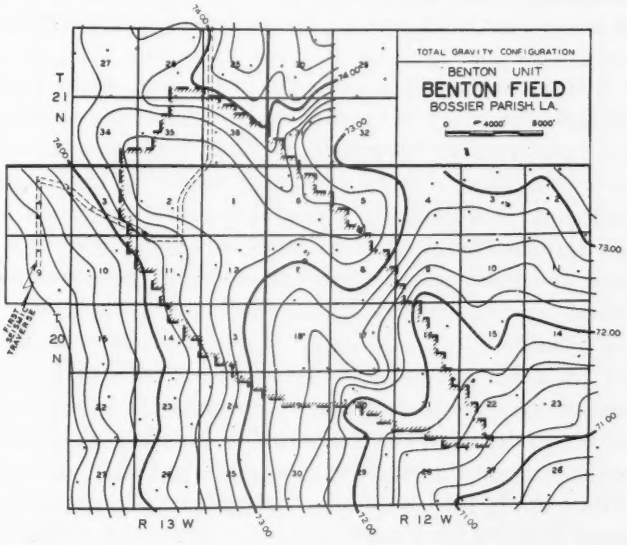

FIG. 2. Total gravity configuration, Benton Unit, Benton Field, Bossier Parish, La.

disturbed configuration. (See Fig. 2.) The heavy dashed outline with cross-hatching, shown in Figure 2 and all the following maps, represents the boundary of the Benton Unit Block. It is shown here as a reference guide, since it practically out-

lines the area of production. The gravity anomaly seemed to attain its greatest intensity approximately in the northeast corner of T. 20 N., R. 13 W., and the northwest quarter of T. 20 N., R. 12 W., some five miles northeast of the town of Benton, in Bossier Parish, Louisiana. No attempt was made to extract the regional gradient from the Bouguer gravity picture. However, the highly irregular aspect of this total gravity configuration alone was interpreted as representing a structural trend having a southeast-northwesterly alignment. Bellevue Dome in T. 19 N., R. 11. W., is also on the same trend.

Because the presence of such a trend indicated extremely anomalous conditions in an area characterized by the supposedly undisturbed flank of the Sabine uplift, it was deemed advisable to follow through with a reflection seismograph survey. A National Geophysical Company crew contracted by Barnsdall Oil Company and the Sohio Petroleum Company began a survey on September 20, 1943. The first traverse, shown by a double dashed line, was started just west of the gravity anomaly and was carried eastward to a point situated approximately on the apex of the gravity minimum trend; thence it was carried northward for approximately 3 miles. From the apex of the gravity anomaly west to the beginning of the seismograph traverse, approximately 200 feet of west dip had been observed. North dip, also amounting to approximately 200 feet, still seemed to be present at the northernmost end of the traverse. East dip was regional, and southeast closure some four miles to the south was established during the next few days. By now there remained no doubt that a major structure had been discovered.

Although it is not intended to advocate insufficient detail work, it must be admitted that the delineation of the Benton structure was accomplished with a relatively moderate number of seismic profiles. This was probably due to a number of favorable circumstances, from a seismological as well as a field technological standpoint. A number of well-placed roads and trails facilitated the surveying. No serious trouble was encountered during the shot hole drilling operations, and the holes which were bottomed in the previously mentioned black shale, stood up well. The average shot hole depth was 45 feet and the average charge 3.5 pounds.

A 10-trace reflection seismograph recording set with two seismometers per trace was used along 1,320-foot spreads throughout the prospect. Most of the records varied from fair to good as illustrated in Figure 3. Since the flanks of the structure, particularly on the east side, proved to be rather smooth, a minimum of check or fill-in work, such as 660-foot spreads, was necessary. Furthermore, since continuous profiling work could be carried out without difficulties, very few re-shots had to be taken.

The results of the seismic work are shown on two control horizons. The shallower horizon as illustrated in Figure 4 at an approximate depth of −4,300 feet, is based on correlations of reflections believed to be associated with the base of the anhydrite. The deeper horizon (see Fig. 5), at approximately −8,100

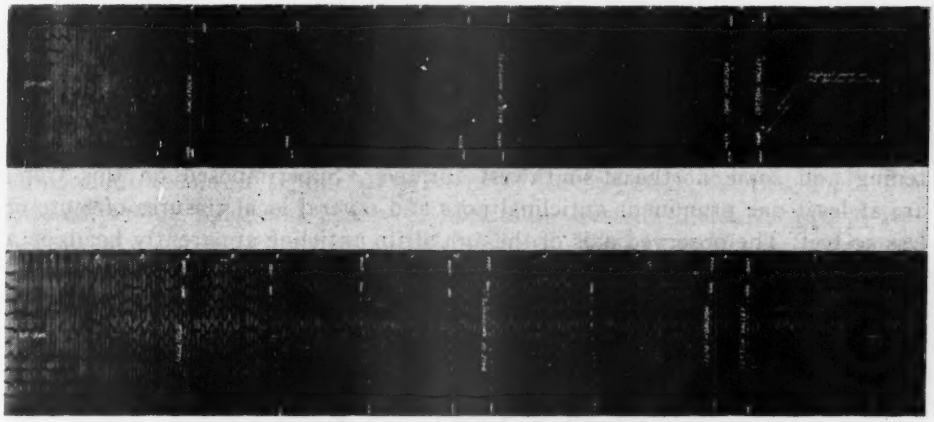

FIG. 3. Typical seismic records, Benton Area, Bossier Parish, La.

feet, representing the configuration of a fairly consistent horizon, was believed to fall in the upper part of the Cotton Valley series. At the time of the survey there was no information from nearby wells which could be used as a guide to determine the exact stratigraphic position of this specific horizon. Therefore no attempts were made to describe it by any other name than "Cotton Valley" control. Furthermore, because the best velocity information available was from the Atlantic Refining Company No. 1 Baker in Columbia County, Arkansas, which is quite a distance from Benton, it was felt that the total depth measurements

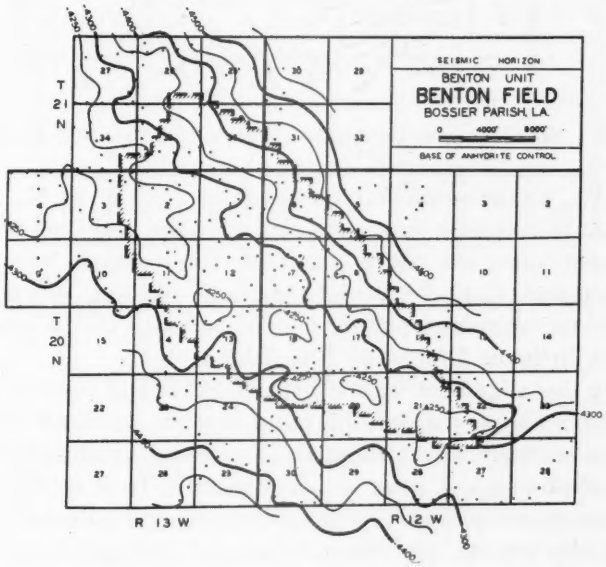

FIG. 4. Seismic horizon, Benton Unit, Benton Field, Bossier Parish, La.

could be only approximate. However, the relative depths were believed to be accurately determined by the use of this velocity value.

The shallow horizon depicting the base of the anhydrite control as shown in Figure 4 does not indicate the presence of major structural closure at that depth. However, there a distinct ridge is visible characterized by a broad zone of flattening and some northeast-southwest turnover. Superimposed on this trend are at least one prominent anticlinal nose and several local closures of more or less 50 feet. The observed axis of the anhydrite anticline apparently heads in a northwest-southeasterly direction from the center of the west line of Sec. 34, T.

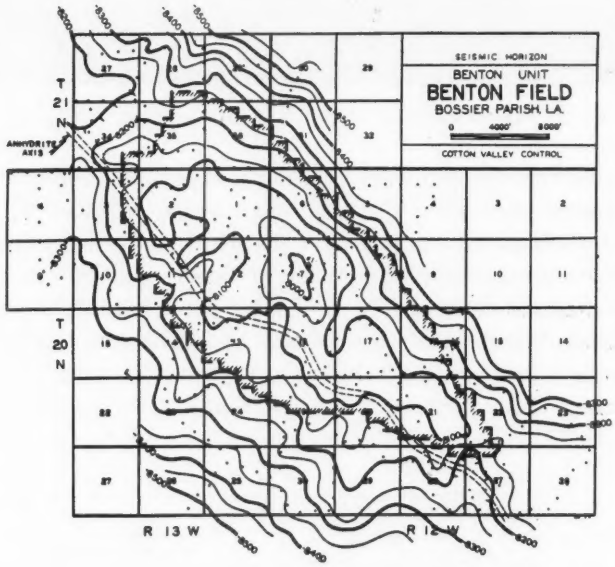

FIG. 5. Seismic horizon, Benton Unit, Benton Field, Bossier Parish, La.

21 N., R 13 W., to the southwest corner of Sec. 21, T. 20 N., R 12 W. The reflections from this horizon have good character and excellent continuity. East dip is prominent along the entire length of the structure. West dip is rather weak in most places, and critical northwest and southeast dip practically nonexistent. Thus the anhydrite picture merely indicates that a structural bridge exists between Bellevue Dome and Pine Island.

Comparing this alignment with the structural axis of the Cotton Valley picture illustrated in Figure 5, a shift down dip or to the northeast is apparent. The maximum displacement occurs along a hypothetical southwest-northeast cross section through the highest point on the structure. To show this displacement, the axis of the anhydrite anticline is superimposed as a double dashed line on the Cotton Valley picture. The computation and interpretation of several other bands of reflections within the Cotton Valley series, and particularly one control

horizon approximately 600 feet higher than the one shown here, confirmed the interpretation that placed the apex of the deep-seated structure in Sec. 7, T. 20 N., R. 12 W.

The character of the reflection for the −8,100 foot horizon, although not quite as excellent as that of the anhydrite reflection, nevertheless was good throughout the most significant portions of the structure. At this depth considerably more relief was observed. Maximum west dip amounts to 550 feet, northwest dip to over 250 feet, and southeast dip to 200 feet. Total regional east dip was not established, since it was still obvious and persistent at the ends of the traverses shot in this direction. On the strength of this information, a drill site near the center of Sec. 7, T. 20 N., R. 12 W., was recommended. A well drilled in the southwest quarter of the northeast quarter of this section resulted in the discovery and production of gas distillate on the Benton structure. Sixteen additional wells confirmed rather closely the extent, shape and relief of the structure as predicted by the seismograph work.

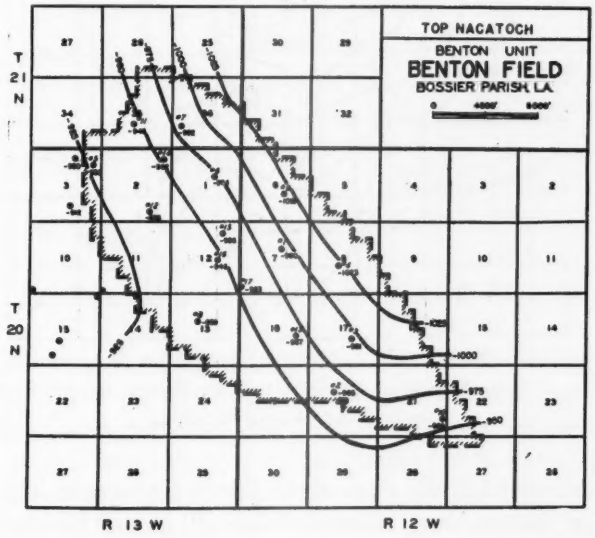

FIG. 6. Top Nacatoch, Benton Unit, Benton Field, Bossier Parish, La.

GEOLOGICAL DATA AND MAPS

The Benton structure as mapped on the top of the Nacatoch formation shown in Figure 6 shows only gentle dip to the northeast of 50 feet per mile in the area overlying the deep-seated structure, and only 25 feet per mile over the northwest flank of the deeper fold. The effect of the Sabine uplift is well illustrated here by the tilt it has given the Benton structure. The top of the Nacatoch formation is approximately 120 to 140 feet below the top of the Arkadelphia marl, which is

the topmost member of the Upper Cretaceous. This contact is represented by the regional unconformity between the Upper Cretaceous of the Mesozoic age and the overlying Midway shale, which is basal Cenozoic in age. The top of the Nacatoch in the Benton Field is approximately 250 feet lower than Pine Island and 900 feet lower than Bellevue.

Figure 7 is an isopachous map between the Top Nacatoch and Top Paluxy. It shows the combined thickness of all but one of the formations composing the Upper Cretaceous. The Arkadelphia marl, which is from 120 to 140 feet in thickness, was omitted because of difficulty in picking the top from electric logs. The top of the Paluxy formation is represented here by an erosional uncon-

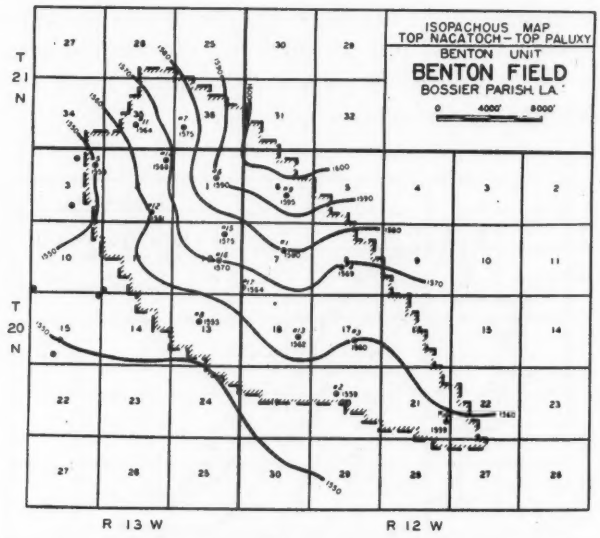

FIG. 7. Isopachous Map, Top Nacatoch-top Paluxy, Benton Unit, Benton Field, Bossier Parish, La.

formity which occurred at the close of the Lower Cretaceous and which marked a time of major diastrophism. Note that the well having the thinnest section is Unit Well No. 5, located in the northwest corner of the field. As will be shown later, this well is the lowest on the Jurassic formation of any well in the field. The absence of thinning of the Upper Cretaceous sediments over the structure shows that Benton had received almost its full growth by the close of the Lower Cretaceous. This same interval at Bellevue is approximately 100 feet thinner at the highest point of structure, thus showing that Bellevue did receive some growth during the Upper Cretaceous. At Pine Island, this interval is approximately 200 feet thinner than at Benton, thus showing growth of that magnitude at Pine Island during the Upper Cretaceous. It was this growth of the Sabine uplift during this period which caused Unit Well No. 5, the closest well to the

uplift, to have a thinner section. This growth was also responsible for tilting Benton to the northeast.

Figure 8 illustrates the structure at Benton as mapped upon the base of the Ferry Lake anhydrite of approximate middle Lower Cretaceous age. This formation is widely used for regional sub-surface mapping, and it also provides one of the best reflecting horizons for the seismograph. Note that the first evidence of the possibility of a deep-seated structure at Benton is first revealed by formations in the Lower Cretaceous. Here again Unit Well No. 5 in the northwest corner of the field is shown to be the highest well on structure, which was caused

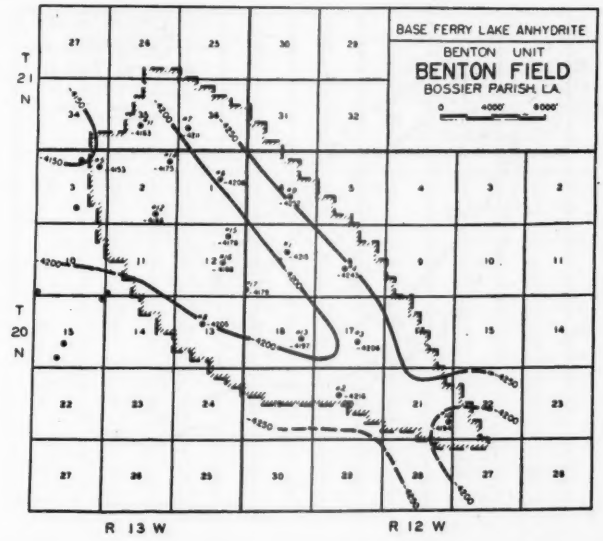

FIG. 8. Base Ferry Lake Anhydrite, Benton Unit, Benton Field, Bossier Parish, La.

this time not by faster growth of the Sabine uplift during deposition of the Lower Cretaceous sediments, but solely because of the enormous growth of the uplift at the end of the Lower Cretaceous, when Benton had almost ceased its growth. As a matter of fact, the Lower Cretaceous beds remaining at Pine Island are 150 feet thicker than the same beds in the highest well at Benton, thus showing Benton to have had much greater relative growth during this time. As an illustration of the relative magnitude of the rise of the Sabine uplift at the close of the Lower Cretaceous, information shows that approximately 400 feet of Upper Glen Rose and all of the 850 feet of Paluxy now present at Benton were removed by erosion at Pine Island. This shows a rise of 1,250 feet more than Benton.

A comparison of Benton with Bellevue indicates the remaining Lower Cretaceous beds at Bellevue to be from 50 to 175 feet thicker than the same age beds at Benton, thus showing much greater relative growth of structure at Benton

during the Lower Cretaceous. Here again, however, Bellevue, like the Sabine uplift, received an enormous uplift at the close of the Lower Cretaceous which resulted in over 2,300 feet of beds, of this age now present at Benton, being removed by erosion at Bellevue. It is this uplift which is believed to be responsible for a slight tilt of the southeast end of the Benton structure, which is shown by Unit Well No. 10, the closest well to Bellevue. This well is slightly higher on both the Top of Nacatoch and Base cf Ferry Lake Anhydrite than the several wells immediately to the northwest.

The absence of closure on the Ferry Lake anhydrite explains the lack of

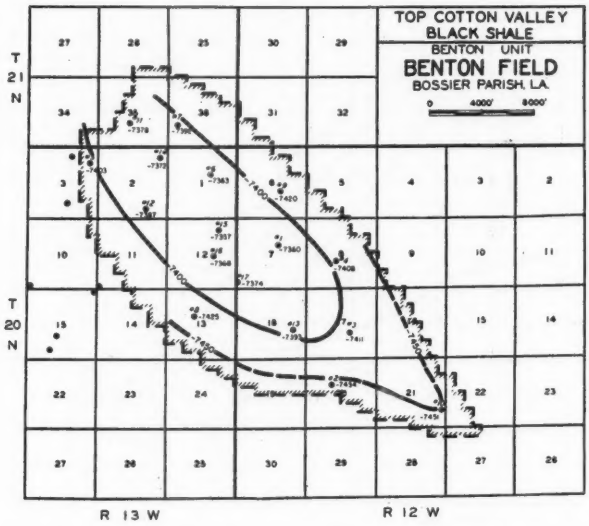

FIG. 9. Top Cotton Valley black shale, Benton Unit, Benton Field, Bossier Parish, La.

productions at Benton in the often prolific producing horizons in the Rodessa Lime Series of Lower Glen Rose age. Note that the axis of the structure as shown on this horizon extends from the northeast corner of Section 3 southeastward to the approximate center of Section 21. As will be shown later, the axis of the main portion of the deep-seated structure is located considerably northeastward, but both axes converge approaching Section 21 at the southeast end of the field. Benton is about 1,700 feet lower than Pine Island on the Ferry Lake anhydrite and about 3,250 feet lower than the restored elevation of this formation at Bellevue. Thus it is evident that although Benton, Bellevue and Pine Island were relatively quiescent during the Upper Cretaceous, later folding during the Cenozoic gave Pine Island an additional 300 feet of uplift; Bellevue an additional 800 feet; and Benton only a very few feet, if any.

The structure map of the Top of Cotton Valley Black Shale, shown in Figure 9, depicts the present structure of Benton as determined by the top of a 20-foot

bed of grey-black shale occurring about 100 feet below the top of the Cotton Valley formation of the Upper Jurassic. The unconformity existing between the Cotton Valley and the overlying Travis Peak formation of the basal Upper Cretaceous is only slightly apparent at Benton. The structure on this horizon shows only 18 feet of actual closure, although more closure is probably present. Note that the axis of the structure is now shown to extend from the northwest corner of Section 35 southeastward to the southeast corner of Section 21.

Figure 10, which is an isopachous map between the Paluxy and the Cotton Valley, illustrates the growth of the Benton structure during deposition of the Lower Cretaceous sediments. Note that Unit Well No. 1 has 4,790 feet of Lower

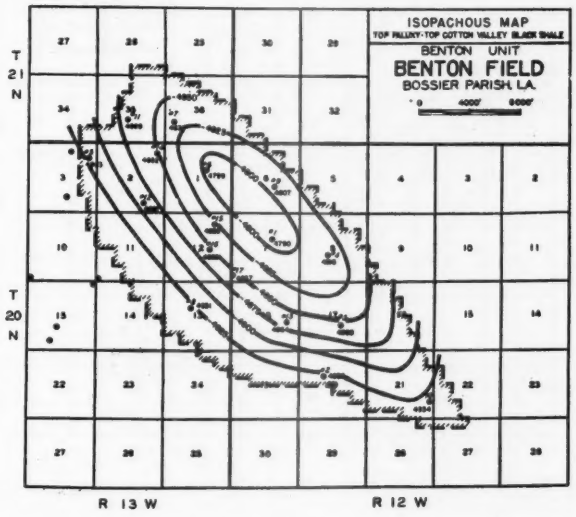

FIG. 10. Isopachous map, top Paluxy-top Cotton Valley black shale, Benton Unit, Benton Field, Bossier Parish, La.

Cretaceous while Unit Well No. 10 has a total of 4,934 feet or a difference of 144 feet, which represents, as a minimum, the growth of the Benton structure during this time.

Figure 11 shows the structure of the Benton Field as mapped upon the top of the Bodcaw Sand of Cotton Valley Age. This sand is one of the two producing sands in the field, the other being the "D" Sand lying about 110 feet above the Bodcaw. The actual closure shown is 61 feet by present well control. However, further drilling to the northwest of the field would undoubtedly show a much greater amount of closure. The interval from the top of the Black shale to the top of the Bodcaw sand varies from 467 feet in Unit Well No. 10 to 526 feet in Unit Well No. 5, a difference of 59 feet. This difference represents the growth of the Benton structure during deposition of the upper 500 feet of the Cotton Valley formation of Upper Jurassic age. Note that the axis of the structure is

now shown to extend from slightly southwest of the center of Section 35 southeastward to the southeast corner of Section 21. This axis is over one-half mile northeast of the axis shown by the structure mapped on the base of the Ferry Lake anhydrite.

The deepest penetration of the Cotton Valley formation was in Unit Well No. 3, which was drilled to a depth of 9,307 feet or 1,597 feet below the top of the Cotton Valley Black Shale. It is estimated that the Smackover formation of Jurassic Age would be encountered at Benton at about 10,700 feet.

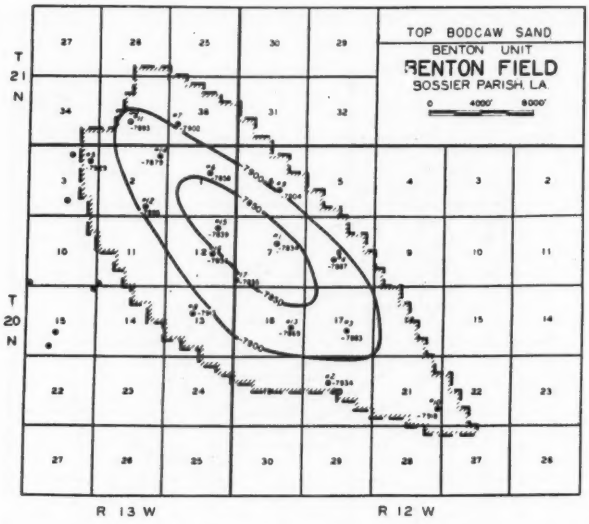

FIG. 11. Top Bodcaw Sand, Benton Unit, Benton Field, Bossier Parish, La.

COMPARISON OF SEISMOGRAPH AND SUB-SURFACE STRUCTURE MAPS

Figure 12 shows the comparison of structure mapped on the base of the Ferry Lake Anhydrite by sub-surface geology and by seismograph. Seismograph contouring is shown in solid black lines and sub-surface contouring in dashed lines. Fifty-foot contours have been used for both sets of data. Note that the structural axis as determined by both seismograph and sub-surface geology is identical. Note also that seismograph data show many minor folds and configurations of structure which are not possible to map by sub-surface geology based on only 17 wells. The seismograph shows the dip on the northeast flank to be about twice as steep as actually exists, but lack of well control prevents any direct comparison on the southwest flank.

Figure 13 shows the comparison of structure mapped on the top of the Bodcaw sand by sub-surface geological methods and on a reflecting horizon presumed to be about 200 feet below the Bodcaw sand at about the level of the "F" or Davis sand. A contour interval of 50 feet was used for both methods. Note that

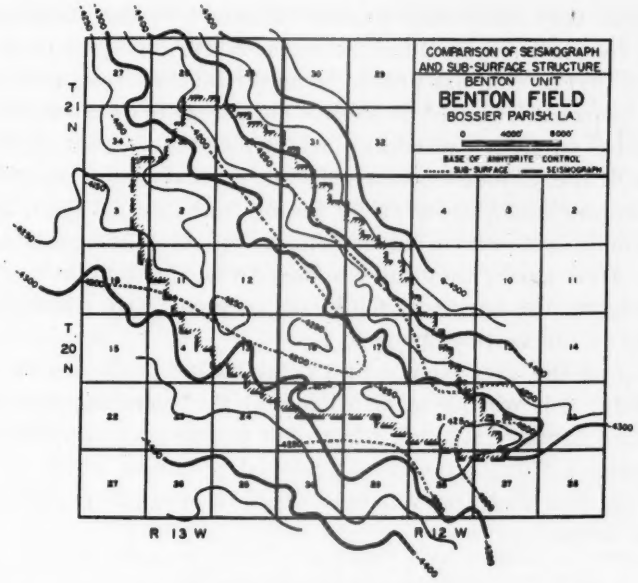

FIG. 12. Comparison of seismograph and sub-surface structure, Benton Unit, Benton Field, Bossier Parish, La.

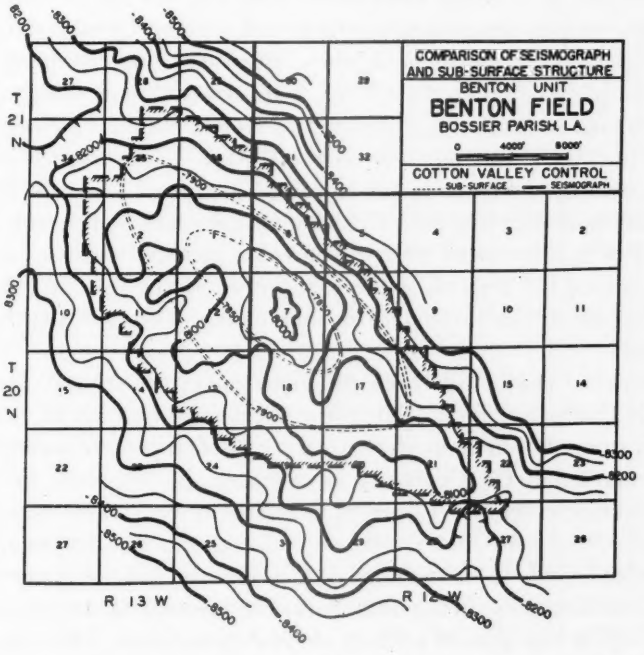

FIG. 13. Comparison of seismograph and sub-surface structure, Benton Unit, Benton Field, Bossier Parish, La.

the seismograph very accurately located the crest of the structure to be in Section 7 and the discovery well located in the Southwest quarter of the Northeast quarter of that section has proved to be the highest well in the field.

Although the contours based on seismic data seem to be more closely spaced, this appearance is partially caused by the fact that the well data did not happen to coincide with the 50-foot contour interval, so that the actual differences in structural elevation could be shown by the contour interval used. Seismic data show many minor folds which did not appear on sub-surface control based on only 17 wells. Here again, they show almost twice the amount of dip which is actually present on the northeast flank but very correctly show the measured amount of dip on the southwest flank.

As evidence of the effectiveness of a combination of the use of seismic and sub-surface data, it is worthy of mention that the operating agreement which became effective January 1, 1946, when only 5 wells had been drilled, covered an area comprising 8,913 acres. Two years later, during which 12 more wells were drilled, the final unit area was established to be 9,548.92 acres, an increase of only 635.92 acres.

HISTORY OF DEVELOPMENT

In order to demonstrate the practical value of knowing in advance the approximate outlines of a newly discovered field, the history of development of Benton is presented in chronological order, and its step-by-step development is just as interesting as its geologic history. Barnsdall Oil Company and Sohio Petroleum Company completed their No. 1 Hanks well, now designated as Unit Well No. 1, located in Section 7, Township 20 North, Range 12 West, on October 20, 1944, in the "D" sand member of the Cotton Valley formation of Upper Jurassic age, through perforations at 8,001 to 8,040 feet. The well flowed at the rate of 170 barrels of 61.7 degree A.P.I. condensate per day, through one-quarter inch choke. The Bodcaw sand was proven to be productive by a drill-stem test taken at 8,114 to 8,150 feet when the well flowed at the rate of 108 barrels per day of 58.4 degree through one-quarter inch choke. The total depth of the well was 8,762 feet.

On January 1, 1946, the three principal operators in the field—namely, Barnsdall Oil Company, Sohio Petroleum Company and G. H. Vaughn—put into effect a unit operation agreement covering their respective leasehold interests and naming Barnsdall Oil Company as operator. At the time this agreement became effective, the field development consisted of only three producing wells, Nos. 1, 3 and 6; one semi-commercial well, No. 5; and one dry hole, No. 2. The choice of the leaseholds to be included, which determined the percentage ownership of the three companies in the unit operation, was very largely governed by the seismic data which had proved already to be very accurate. The area included in this agreement comprised 8,913 acres. The three operators also agreed at this time to drill eight additional wells at locations selected very largely by seismic data.

Shortly after the operating agreement became effective, a hearing was held on March 14, 1946, before the Department of Conservation, State of Louisiana, at which the boundaries of the Unit were approved by the Commission and an order was entered providing for unitization of the leasehold and mineral and royalty interests and for cycling the "D" and Bodcaw sands. At this time seven wells had been completed, of which five were producers, one was semi-commercial, and three wells were then drilling. As a result of the information gained by the completion of two more wells since the effective date of the operators agreement, the boundary of the Unit was increased by approximately 1,235 acres to a total of 10,150 acres. In order to secure additional data for determination of equities, the Commission's Order stipulated and required the drilling of the four additional wells at the locations suggested by the operators. Although the choice of these locations was very largely determined by sub-surface geological data, by that time available, it was still greatly influenced by the seismic data.

Twenty months after the original hearing, a second hearing was held before the Department of Conservation on November 20, 1947, at which time a total of 15 wells had been drilled within the unitized area, of which 12 were producers, one was a semi-commercial producer and two were dry holes. The unit boundaries were again revised to a total of 9,548.92 acres, a reduction of approximately 600 acres from the Unit Area determined at the first hearing. The first determination of equities were made at this time by the firm of DeGolyer and McNaughton, which had been employed by the operators for this purpose and whose findings, based on estimates of hydrocarbons in place, were approved by the Department of Conservation.

A third hearing before the Department of Conservation was held on December 17, 1948, at which time a total of 17 wells had been drilled in the Unitized Area, of which 14 were producers, one was a semi-commercial producer and two were dry holes. No further drilling has been done in the Unit Area to date. The unit boundaries were not revised at this hearing and remain to date as comprising 9,548.92 acres. At this hearing the Commissioner approved the revision of equities as prepared by the firm of DeGolyer and McNaughton. They estimated that the total recoverable reserves for the field were 187,494,163,000 cubic feet of gas and 16,766,401 barrels of liquid products. Some eleven months previous to this time a cycling plant, built by the operators, had been put into operation on January 27, 1948, with a capacity of 50,000,000 cubic feet of gas per day. Prior to commencement of plant operations the field had produced a total of 3,675,565,000 cubic feet of gas and 17,445 barrels of oil. In the first two years of plant operation during the period from February 1, 1948, to February 1, 1950, the field produced 39,343,661,000 cubic feet of gas, of which a total of 34,420,257,000 cubic feet was returned to the two producing sands. From the gas produced, the plant recovered a total of 3,231,342 barrels of liquid products or approximately 82 barrels per million cubic feet of gas.

SUMMARY AND CONCLUSION

The two producing horizons in the Benton Field are the "D" sand and the Bodcaw sand. Both are members of the upper portion of the Cotton Valley formation of Jurassic age. The "D" sand occurs about 450 feet below the top of the Cotton Valley and varies in thickness from 36 feet in the northwest central portion of the field to only one foot in Unit Well No. 11 in the extreme northwest corner of the field. The Bodcaw sand occurs approximately 110 feet below the "D" sand and varies in thickness from 25 feet in the northwest central portion of the structure to zero feet in the same Unit Well No. 11. Both the "D" and Bodcaw sands have developed their greatest thickness on the crest of the structure, which is the condition to be expected since the fold was steadily rising during the time of deposition of these sands. Both sands produce gas-condensate and, in addition, the Bodcaw has an eighteen foot oil column lying below the gas cap.

The development of the Benton Field is outstanding in the oil and gas industry with regard to efficiency of operations, minimum development costs and utilization of the latest and most modern methods of engineering technique both in well equipment, flow lines, design of cycling plant and in production problems. These were all made possible by consolidation of leasehold interests very early in the development of the field to the effect that all operations were designed to complete the development with regard only to the field as a whole. Such consolidation, at a time when only five wells had been drilled, was made possible only because seismic data had already demonstrated its extremely close definition of the structure. This permitted the delineation of the estimated producing limits of the field to be agreed upon readily and leasehold equities tentatively established upon a basis allowing further development for the benefit of all. The unusually complete and detailed determination of final equity percentages was made possible only because of extremely careful coring of the producing sands and subsequent core analysis and production tests.

ACKNOWLEDGMENTS

The authors hereby express their appreciation to Barnsdall Oil Company, Sohio Petroleum Company, and G. H. Vaughn for permission to publish the data presented in this paper.

THE SECOND DERIVATIVE METHOD OF GRAVITY INTERPRETATION*

THOMAS A. ELKINS†

ABSTRACT

The second derivative method of interpreting gravity data, although its use is justifiable only on data of high accuracy, offers a simple routine method of locating some types of geologic anomalies of importance in oil and mineral reconnaissance. The theoretical formula by which it is possible to compute the second (vertical) derivative of any harmonic function from its values in a horizontal plane is derived for both the two-dimensional and the three-dimensional cases. The graphical method of computing the second derivative is discussed, especially as to the sources of error. A numerical coefficient equivalent of the graphical method is also presented.

Formulas and graphs for the second derivative of the gravity effect of such geometrically simple shapes as the sphere, the infinite horizontal cylinder, the semi-infinite horizontal plane, and the vertical fault, are presented with discussions of their value in the interpretation of practical data. Finally, the gravity and second derivative maps of portions of some important oil provinces are presented and compared to show the higher resolving power of the second derivative.

IMPORTANCE OF SECOND DERIVATIVE

The second derivative we shall discuss in this paper is the second vertical derivative of *gravity;* more exactly, of the vertical component of gravity, which is the quantity measured by gravimeters and pendulums. If we use the symbol g to denote gravity and choose axes so that z is vertically downward, then the second derivative is the quantity $\partial^2 g/\partial z^2$.

The importance of the second derivative for gravity interpretation arises from the fact that the double differentiation with respect to depth tends to emphasize the smaller, shallower geologic anomalies at the expense of larger, regional features. The second derivative picture is therefore often a clearer and better resolved picture of the type of anomalies which are important in oil or mineral exploration than is the original gravity picture.

It was for this reason that studies of the application of the second derivative to gravity data were started at the Gulf Research Laboratories late in 1935, when gravimeter data of sufficient accuracy to warrant such analysis began to become available. Routine calculations of the second derivative of gravity were being carried out in 1936. In this paper, no attempt is made to present a comprehensive account of this work. The purpose is merely to present a few useful fundamental points with practical illustrations from some important oil provinces.

BASIC THEORY, THREE-DIMENSIONAL CASE

Although the basic theory of the second derivative has already been published (Peters, 1949), it arose there merely as a by-product of the theory of continuation

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downward. It thus seems worth-while to present the basic second derivative theory on an independent basis, for the use of those who may not wish to familiarize themselves with a more general theory.

Although we shall apply it only to gravity, the theory we present is applicable to any harmonic function, $H(x, y, z)$, that is, any function with continuous second derivatives which satisfies Laplace's equation

$$\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} + \frac{\partial^2 H}{\partial z^2} = 0, \tag{1}$$

in the neighborhood of the point (0, 0, 0) at which we desire the value of the second vertical derivative, $[\partial^2 H/\partial z^2]_{x=y=z=0}$, for which we have data available in the horizontal plane, $z=0$.

Let us define a function $\overline{H}(r, z)$ by the equation

$$\overline{H}(r, z) = \frac{1}{2\pi}\int_0^{2\pi} H(r\cos\theta, r\sin\theta, z)d\theta. \tag{2}$$

We shall denote the value of $\overline{H}(r, z)$ for $z=0$ by $\overline{H}(r)$. That is

$$\overline{H}(r) = \frac{1}{2\pi}\int_0^{2\pi} H(r\cos\theta, r\sin\theta, 0)d\theta. \tag{3}$$

$\overline{H}(r)$ is the average value of $H(x, y, z)$ around a circle of radius r in the plane $z=0$ with the origin as center. Since $H(x, y, z)$ is a harmonic function in the neighborhood of the origin, it may there be expanded in a convergent power series in the variables x, y, z. Consequently $\overline{H}(r)$ may be expanded in a power series in r about $r=0$,

$$\overline{H}(r) = a_0 + a_2 r^2 + a_4 r^4 + \cdots, \tag{4}$$

where all the odd powers of r are missing, since in the integration of equation (3), terms of the form $\sin^m\theta\cos^n\theta$, where $m+n$ is odd, integrate to zero, because the period of $\sin\theta$ and $\cos\theta$ is 2π.

It is by making use of $\overline{H}(r)$ that we shall compute the second vertical derivative of $H(x, y, z)$. From (1) we have

$$\frac{\partial^2 H}{\partial z^2} = -\left(\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2}\right).$$

If we make the substitution: $x=r\cos\theta$, $y=r\sin\theta$, we have

$$\frac{\partial^2 H}{\partial z^2} = -\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial\theta^2}\right)H. \tag{5}$$

Let us integrate both sides of equation (5) with respect to θ between the limits of 0 and 2π. Then, for $r>0$,

$$\int_0^{2\pi} \frac{\partial^2 H}{\partial z^2}\, d\theta = -\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\int_0^{2\pi} H d\theta - \frac{1}{r^2}\int_0^{2\pi} \frac{\partial^2 H}{\partial \theta^2}\, d\theta.$$

The last term integrates to

$$-\frac{1}{r^2}\frac{\partial H}{\partial \theta}\Bigg]_0^{2\pi}$$

and vanishes since $\partial H/\partial\theta$ is a series in which θ appears only in terms like $\sin^m\theta$ $\cos^n\theta$ where m and n are integers (only one of which may be zero). Therefore,

$$\int_0^{2\pi} \frac{\partial^2 H}{\partial z^2}\, d\theta = -\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\int_0^{2\pi} H(r\cos\theta, r\sin\theta, z)d\theta. \tag{6}$$

If we let $z=0$ in equation (6), we have

$$\frac{1}{2\pi}\int_0^{2\pi}\left(\frac{\partial^2 H(r\cos\theta, r\sin\theta, z)}{\partial z^2}\right]_{z=0} d\theta$$

$$= -\frac{1}{2\pi}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\int_0^{2\pi} H(r\cos\theta, r\sin\theta, 0)d\theta$$

$$= -\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\overline{H}(r). \tag{7}$$

If now we let r approach 0 in equation (7) and make use of equation (4), we have

$$\frac{1}{2\pi}\int_0^{2\pi}\left[\frac{\partial^2 H(r\cos\theta, r\sin\theta, z)}{\partial z^2}\right]_{r=z=0} d\theta = \left[\frac{\partial^2 H(x, y, z)}{\partial z^2}\right]_{x=y=z=0}$$

$$= \left[-\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\overline{H}(r)\right]_{r=0} = -4a_2.$$

We therefore have the basic formula:

$$\left[\frac{\partial^2 H(x, y, z)}{\partial z^2}\right]_{x=y=z=0} = -4a_2. \tag{8}$$

This formula leads immediately to the graphical method of finding the second derivative. For, if we pick some point P in the plane $z=0$ as a center and plot the average value of H in this plane around a circle of radius r as ordinate against r^2 as abscissa, the slope of this curve is the derivative of $\overline{H}$ with respect to r^2. From equation (4) we see that the value of the slope at the origin is a_2; thus the value of $\partial^2 H/\partial z^2$ at P is found by multiplying the slope at the origin for this curve by -4.

BASIC THEORY, TWO-DIMENSIONAL CASE

By the two-dimensional case, we mean that in which the potential function

does not involve one of the horizontal coordinates, say the y coordinate. Since in this case Laplace's equation (1) becomes:

$$\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial z^2} = 0,$$

we then have:

$$\frac{\partial^2 H}{\partial z^2} = -\frac{\partial^2 H}{\partial x^2}. \tag{9}$$

Thus we can compute the second vertical derivative as the negative of the second horizontal derivative along a profile for which y has a constant value.

However, it seems advantageous to have a uniform procedure which is the same for both the two and three-dimensional cases since, with practical data, rigorously two-dimensional features cannot occur because all geologic features are necessarily of finite length. We shall therefore apply the three-dimensional procedure to the two-dimensional case and prove that it yields the correct result. That is, instead of using data only along the single two-dimensional profile, we imagine the horizontal plane filled up with the profile values as the whole profile moves in the direction of the y axis but always remaining parallel to itself.

Since in the two-dimensional case $H(x, y, z)$ is assumed to be a harmonic function of the variables x and z, but independent of y, in the neighborhood of the origin, there exists an expansion valid for small enough values of x of the form

$$H(x, y, 0) = b_0 + b_1 x + b_2 x^2 + \cdots, \tag{10}$$

where no terms in y occur, since this is the two-dimensional case. Further,

$$b_2 = \frac{1}{2}\left[\frac{\partial^2 H}{\partial x^2}\right]_{x=y=z=0} = -\frac{1}{2}\left[\frac{\partial^2 H}{\partial z^2}\right]_{x=y=z=0}, \tag{11}$$

by equation (9). After we make the substitution $x = r\cos\theta$, $y = r\sin\theta$, equation (10) becomes

$$H(x, y, 0) = b_0 + b_1 r\cos\theta + b_2 r^2\cos^2\theta + \cdots$$

and the integral of equation (3) is:

$$\overline{H}(r) = b_0 + \frac{b_2 r^2}{2} + \cdots. \tag{12}$$

We now have the radial expansion $\overline{H}(r)$ and according to the basic equation (8) of the three-dimensional theory, the second derivative at the origin is found by taking the negative of four times the coefficient of the r^2 term in $\overline{H}(r)$. But this quantity $= -4(b_2/2) = -2b_2$, which by equation (11) $= [\partial^2 H/\partial z^2]_{x=y=z=0}$, which is the correct value. Thus carrying out the three-dimensional process mechanically on the two dimensional data leads to the correct answer. Conse-

quently the use of the three-dimensional method on the extended two-dimensional data is valid.

AVERAGE RADIAL GRAVITY

Since the graphical method of computing the second derivative of gravity is based on the average radial gravity as given in equation (4), we shall first study this quantity for the fundamental types of two and three-dimensional mass anomalies, the infinite horizontal cylinder and the sphere, respectively.

Average radial gravity for the infinite horizontal cylinder

Let d be the depth to the axis of the cylinder and g_M the maximum gravity.

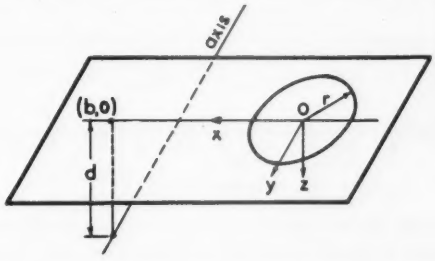

FIG. 1. Notation for study of infinite horizontal cylinder.

If the point O around which the average radial gravity is to be found is directly above the axis of the cylinder, then, using the notation of Figure 1, the average radial gravity, $\bar{g}(r)$ is given by

$$\bar{g}(r) = \frac{1}{2\pi}\int_0^{2\pi} \frac{d^2 g_M d\theta}{x^2 + d^2} = \frac{1}{2\pi}\int_0^{2\pi} \frac{d^2 g_M d\theta}{d^2 + r^2\cos^2\theta} = \frac{g_M}{\sqrt{1 + (r/d)^2}}.$$

The curve in Figure 2 for $b=0$ is plotted from this equation.

If the point O is off center, suppose the projection of the axis passes through the point $(b, 0)$. Then

$$\bar{g}(r) = \frac{1}{2\pi}\int_0^{2\pi} \frac{d^2 g_M d\theta}{d^2 + b^2 - 2br\cos\theta + r^2\cos^2\theta} = \frac{g_M\sqrt{1 + k^2 y_1}}{\sqrt{(1 + k^2 + m^2)^2 - 4m^2k^2}},$$

where $k=r/d$, $m=b/d$, and y_1 is the positive root of the equation in μ,

$$k^2\mu^2 - (k^2 - m^2 - 1)\mu - 1 = 0.$$

The curves in Figure 2 for $b=0.4d$ and $b=d$ were plotted from this equation.

Average radial gravity for the sphere

Let d be the depth to the center of the sphere and g_M the maximum gravity. If the point O is directly over the center, P, of the sphere, then

$$\bar{g}(r) = d^3 g_M/(r^2 + d^2)^{3/2}.$$

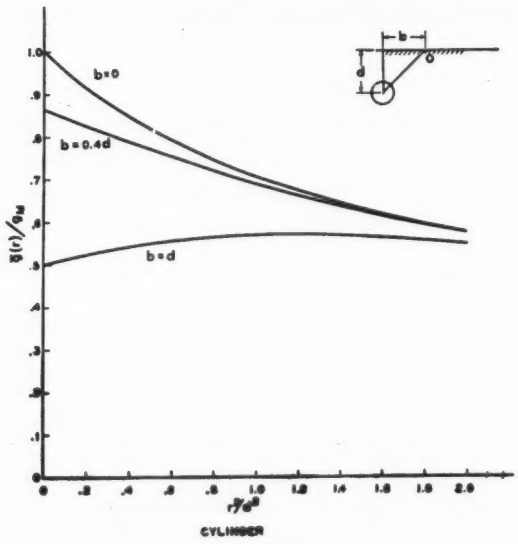

FIG. 2. Profiles of average radial gravity, $\bar{g}(r)$, for infinite horizontal cylinder. Averages are around circles (in the horizontal plane) of radius r centered on point O; g_M is the maximum gravity.

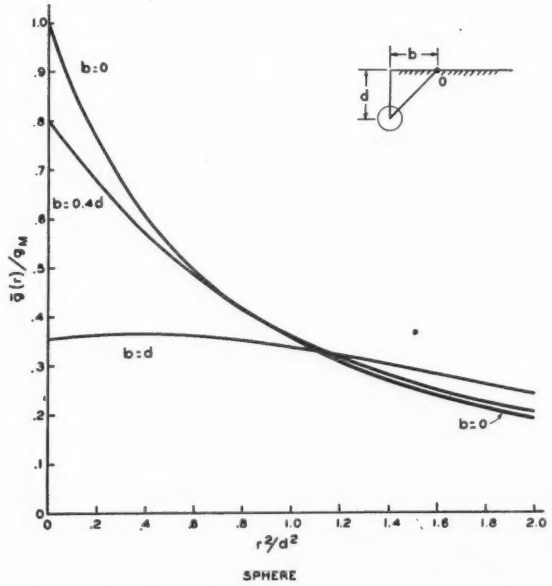

FIG. 3. Profiles of average radial gravity, $\bar{g}(r)$, for sphere. Averages are around circles (in the horizontal plane) of radius r centered on point O; g_M is the maximum gravity.

The curve in Figure 3 for $b=0$ is plotted from this formula.

If the point O is off center, choose axes in as Figure 4 so that the projection of P is $(0, b)$. Then,

$$\bar{g}(r) = \frac{1}{2\pi}\int_0^{2\pi} \frac{d^3 g_M d\theta}{[d^2 + r^2\cos^2\theta + (r\sin\theta - b)^2]^{3/2}}$$

$$= \frac{2d^3 g_M E\left(\sqrt{\dfrac{4br}{d^2 + (r+b)^2}}\right)}{\pi[d^2 + (r-b)^2][d^2 + (r+b)^2]^{1/2}},$$

where $E(k)$ denotes the complete elliptic integral of the second kind with modulus k. The curves in Figure 3 for $b=0.4d$ and $b=d$ are plotted from this equation.

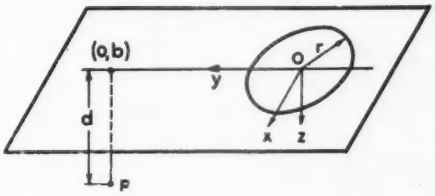

FIG. 4. Notation for study of sphere.

SOURCES OF ERROR IN THE GRAPHICAL METHOD

Using these average value curves we shall now discuss two sources of error in the graphical method of computing the second derivative. The first source of error is the use in practice of a grid array of gravity values to find the average value curve, usually in combination with a chart containing holes punched to match the grid. This process yields only a few isolated points on the curve we are seeking with an accuracy which may be low because of the small number of points read with the chart on the ring for each radius used. The error here may be reduced by increasing the number of rings and the number of points read in each ring. To show graphically the inaccuracies that may be introduced by a grid, portions of Figure 2 have been replotted in Figure 5, which also shows the average values found, using a grid, for a cylinder with maximum gravity 1.5 milligals and depth to axis of 15,000 feet. The averages each used four points, arranged symmetrically. Two averages were computed, one using gravity values correct to 0.1 milligal, the other correct to 0.01 milligal. On the same figure is a similar plot, based on Figure 3, for a sphere with maximum gravity 1.5 milligals and depth to center of 15,000 feet. It will be noted that the averages using gravity data correct to 0.01 milligal (maximum possible error about 0.3 per cent of the maximum value) are close to the correct values, while those using gravity data

correct to 0.1 milligal (maximum possible error about three per cent of the maximum value) often are not.

The second source of error, the non-linearity of the average value curve, is more troublesome. If the portion of the average radial curve (against r^2) near the origin were very nearly a portion of a straight line, it would be easy to draw the correct tangent. However, even with perfectly accurate data and a perfect

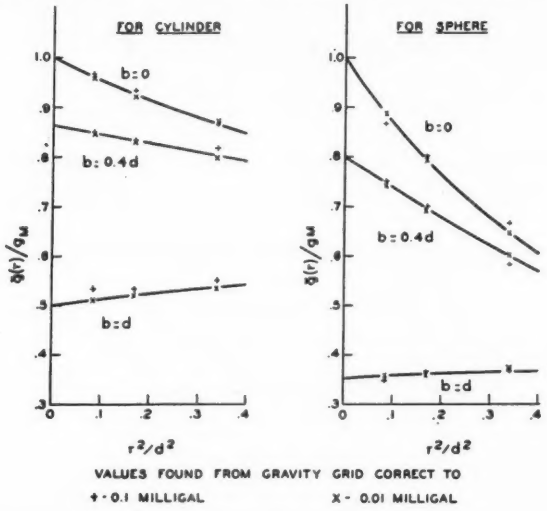

FIG. 5. Average radial gravity values found by use of grid, plotted on profiles from Figures 2 and 3 for comparison.

grid, this part of the radial plot may be definitely curved (as, for example, the curve for $b=d$ in Figure 3). That is, even the theoretical curve is linear only very near the origin. Unfortunately, economic reasons as well as the "noise level" of gravimeter measurements set a lower limit for station spacing so that it is impossible to define the curve at even approximately infinitesimal distances from the origin. Thus it is evident that this is a source of error which is fundamental.

A study of this type of error was made on the same sphere used above in studying the effect of the grid. The point directly above the center of the sphere was the point around which the averages were made. To minimize the non-linearity effect as much as possible only the first ring was used. According to equation (8), an ordinate equal to four times the difference between the gravity at the origin and the first ring average would approximate the value of the second derivative in some unit, just what unit is here immaterial. This unit would vary inversely as the square of the ring radius but all such ordinates for the same radius are comparable, which is sufficient for our present purpose. The following table lists these ordinates. The radial distances are centimeters on a scale 1 inch = 4,000 varas; the depth to the center of the sphere on this scale is 3.429 cms.

Radius of ring, cm.	Ordinate in tenth-milligals			
	Correct theoretical value	Value to give correct value of $\partial^2 g/\partial z^2$	Value found using grid	
			with g correct to 0.1 milligal	with g correct to 0.01 milligal
0.5	1.86	1.91	0	2.0
1	6.91	7.65	8	6.8
$\sqrt{2}$	12.60	15.31	12	12.4
2	21.33	30.62	20	21.2

The non-linearity effect is evident from a comparison of the second and third columns. The superiority of the grid calculations to 0.01 milligal is again clear.

THE NUMERICAL COEFFICIENT EQUIVALENT OF THE GRAPHICAL METHOD

The basic idea of the numerical coefficient method of computing the second derivative has already been published (Peters, 1949). We shall here demonstrate the versatility inherent in the method. We call it the equivalent of the graphical method, since an analytical formulation can be made of any geometric process which may be used in drawing the tangent or other best-fitting line. The coefficient equivalent then has the advantages connected with simple routine calculations and with the avoidance of personal bias.

A coefficient process for finding the value of a_2 in equation (4) and therefore of the second derivative by equation (8), can be developed by choosing r small enough so that $\overline{H}(r)$ is represented to sufficient accuracy by n terms of equation (4). We then have n unknown coefficients a_0, a_2, etc. By using n or more values of r and the corresponding values of $\overline{H}(r)$, we get a set of simultaneous equations from which to find the value of a_2, using least squares or other adjustment processes when there are more equations than unknowns.

It has been found most convenient when a grid of values at a regular spacing s is available to use a chart which has holes for a center reading $\overline{H}(0)$, four readings each at spacings s and $s\sqrt{2}$ and eight readings at spacing $s\sqrt{5}$. We then use the sum of the four readings at s and $s\sqrt{2}$ as an approximation to $4\overline{H}(s) = H'(s)$ and $4\overline{H}(s\sqrt{2}) = H'(s\sqrt{2})$ respectively and the sum of the eight readings at $s\sqrt{5}$ as an approximation to $8\overline{H}(s\sqrt{5}) = H'(s\sqrt{5})$. If the map scale of the grid of values is $1:k$ while the grid spacing is r centimeters (actual measurement on the grid), then $s = kr$.

We shall now drop all but the first two terms of equation (4) and compute three coefficient sets based on different methods of drawing the tangent line for the average radial curve in the graphical method.

First we attempt to find the "best" straight line through the origin which passes through the three points s^2, $2s^2$, $5s^2$; a_0 is then fixed and equals $\overline{H}(0)$, so that the condition equations are:

$$\begin{cases} a_2 s^2 = \overline{H}(s) - \overline{H}(0), \\ 2a_2 s^2 = \overline{H}(s\sqrt{2}) - \overline{H}(0), \\ 5a_2 s^2 = \overline{H}(s\sqrt{5}) - \overline{H}(0). \end{cases}$$

By the method of least squares we find

$$\frac{\partial^2 g}{\partial z^2} = -4a_2 = \frac{1}{60k^2r^2}\left[64\overline{H}(0) - 2H'(s) - 4H'(s\sqrt{2}) - 5H'(s\sqrt{5})\right]. \quad (13)$$

Next we shall drop the favoritism shown the origin and put it on a level with

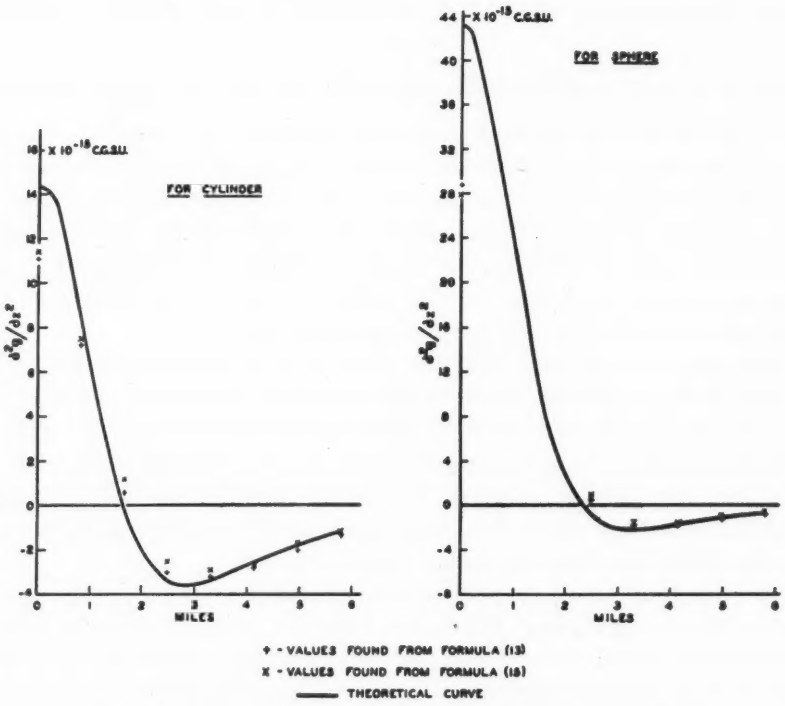

FIG. 6. Tests of second derivative sets on computed gravity data for geometrically simple anomalies.

the other points. That is, we shall determine the "best" straight line through the origin and the three computed points at distances s^2, $2s^2$, $5s^2$. Using the method of least squares we find

$$\frac{\partial^2 g}{\partial z^2} = -4a_2 = \frac{1}{28k^2r^2}\left[16\overline{H}(0) + 2H'(s) - 3H'(s\sqrt{5})\right]. \quad (14)$$

Since in finding the slope graphically we frequently disregard the point at

distance $5s^2$, the computation above was repeated giving the last point only one-half the weight of the other points. The result is

$$\frac{\partial^2 g}{\partial z^2} = -4a_2 = \frac{1}{62k^2r^2}\left[44\overline{H}(O) + 4H'(s) - 3H'(s\sqrt{2}) - 6H'(s\sqrt{5})\right]. \quad (15)$$

From the foregoing it is evident that any number of coefficient sets may be developed. Their relative merits can be determined only by testing them. There should be two kinds of tests. The first should be a test on mathematically accurate data for simple anomalies for which a check against the theoretically correct second derivative values is possible. From this can be found whether or not the approximations involved in the derivation of the formula and the use of a grid cause too great inaccuracy. The second should be a test on actual gravity data to find if the errors in practical data cause too much disturbance.

Tests of both types were applied to the three sets of coefficients here developed. In Figure 6 are shown the results, for two of the sets, of the theoretical tests which were made on a sphere and an infinite horizontal cylinder, both with maximum gravity of 1.5 milligals and depth to center of 15,000 feet. The gravity data used was accurate to 0.01 milligal. From these tests on theoretical anomalies it was concluded that the three sets were equally good. The tests on practical data were judged against values in the same area found by the graphical method. The sets of equations (14) and (15) gave practically the same contours and were very close to the results by the graphical method, while the results of the set of equation (13) were not quite as good.

THE SPHERE

We shall now present equations and graphs for the second derivative effect of several simple types of anomalies. The purpose is to aid in the interpretation of practical second derivative maps. The first anomaly we shall consider is the sphere.

By differentiation of the equation for the potential, we easily find the following equation for the second derivative effect at the origin O:(0, 0, 0) for a sphere of mass m and center $P:(x, y, z)$.

$$\frac{\partial^2 g}{\partial z^2} = 3\gamma mz(2z^2 - 3x^2 - 3y^2)/(x^2 + y^2 + z^2)^{7/2}. \quad (16)$$

Here γ is the gravitational constant. The extreme values, i.e., maxima and minima, of the second derivative occur for $\rho=0$ and $\rho=\pm(2\sqrt{3}/3)z$, where ρ is the radial coordinate along the surface so that $\rho^2=x^2+y^2$. The second derivative at $\rho=0$ is the maximum in absolute value and equals $6\gamma m/z^4$. The other two extremes have the value $-6\gamma m/[7/3]^{7/2}z^4$. Figure 7 shows the second derivative for the sphere as plotted from equation (16).

From equation (16), $\partial^2 g/\partial z^2=0$ when $z=(\sqrt{6}/2)\rho$. We therefore have that

$$z = (\sqrt{6}/2)\rho_0 = 1.225\rho_0, \quad (17)$$

where ρ_0 is the surface distance from the projection of the center, or point of maximum second derivative, to the zero second derivative contour. Let G_M represent the maximum value of the second derivative, which occurs directly over the center of the sphere. Then from equation (16), the radius R of the sphere for density contrast σ, is

$$R = \sqrt[3]{z^4 G_M / 8\pi\sigma\gamma}. \tag{18}$$

Equations (17) and (18) solve the problem of determining a sphere from its second derivative contours when the density contrast is known.

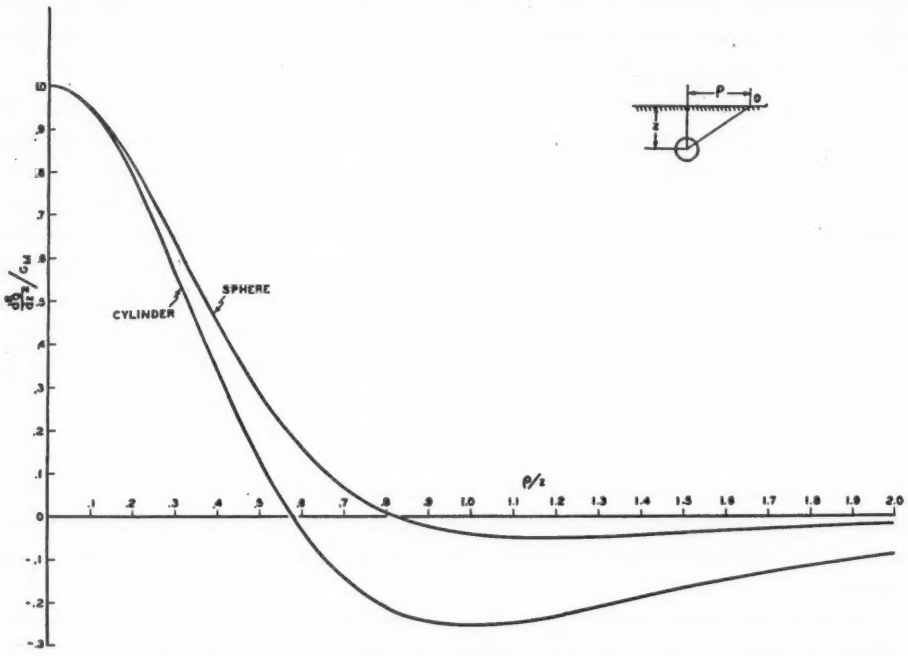

FIG. 7. Second derivative for the sphere and the infinite horizontal cylinder. G_M is the maximum second derivative value, z the depth to the center.

THE INFINITE HORIZONTAL CYLINDER

By integration of equation (16) we find the following equation for the second derivative effect at O:(o, o, o) for an infinite horizontal cylinder of mass m per unit length with axis passing through the point P:(x, y, z) and parallel to the y-axis.

$$\frac{\partial^2 g}{\partial z^2} = 4\gamma m z(z^2 - 3x^2)/(x^2 + z^2)^3. \tag{19}$$

The extreme values occur for $x=0$ and $x=\pm z$, and are $4\gamma m/z^3$ and $-\gamma m/z^3$, respectively. Figure 7 shows the second derivative for the infinite horizontal cylinder as plotted from equation (19).

From equation (19), $\partial^2 g/\partial z^2=0$ when $z=\sqrt{3}x$. We therefore have that

$$z = \sqrt{3}\, x_0 = 1.732 x_0, \tag{20}$$

where x_0 is the surface distance perpendicular to the axis of the cylinder from the projection of the axis, or point of maximum second derivative, to the zero second derivative contour. Let G_M represent the maximum value of the second derivative, which occurs directly over the axis of the cylinder. Then from equation (19), the radius R of the cylinder for density contrast σ, is

$$R = \sqrt{z^3 G_M/4\pi\gamma\sigma}. \tag{21}$$

Equations (20) and (21) solve the problem of determining an infinite horizontal cylinder from its second derivative contours when the density contrast is known.

THE SEMI-INFINITE HORIZONTAL PLANE

This is a two-dimensional structure, independent of the y-coordinate. The typical cross section in Figure 8 is for the plane $y=0$. Let the mass per unit area

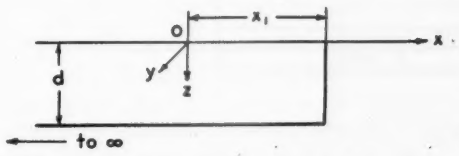

FIG. 8. Notation for study of semi-infinite horizontal plane.

of the plane be m. By integrating equation (19), we find that the second derivative at O is

$$\partial^2 g/\partial z^2 = 4\gamma m dx_1/(x_1^2 + d^2)^2. \tag{22}$$

Figure 9 shows the second derivative plotted from this formula for the case in which d equals one mile and the mass per unit area, m, is that corresponding to a thickness of one-half mile and volume density of 1 gram per cubic centimeter.

The extreme values, from equation (22), are for $x_1=\pm d/\sqrt{3}$ and are $\pm 3\sqrt{3}\gamma m/(4d^2)$, respectively. Thus

$$d = \sqrt{3}\, x_0 = 1.732 x_0, \tag{23}$$

where x_0 is the distance to a maximum or minimum from the zero contour. The problem of determining the elements of a semi-infinite horizontal plane from

its second derivative contours is thus easily solved, first by using equation (23) to find d and then by applying equation (22) to a pair of values of $\partial^2 g/\partial z^2$ and x_1 to find m.

"Condensed" mass distributions of zero thickness do not occur geologically

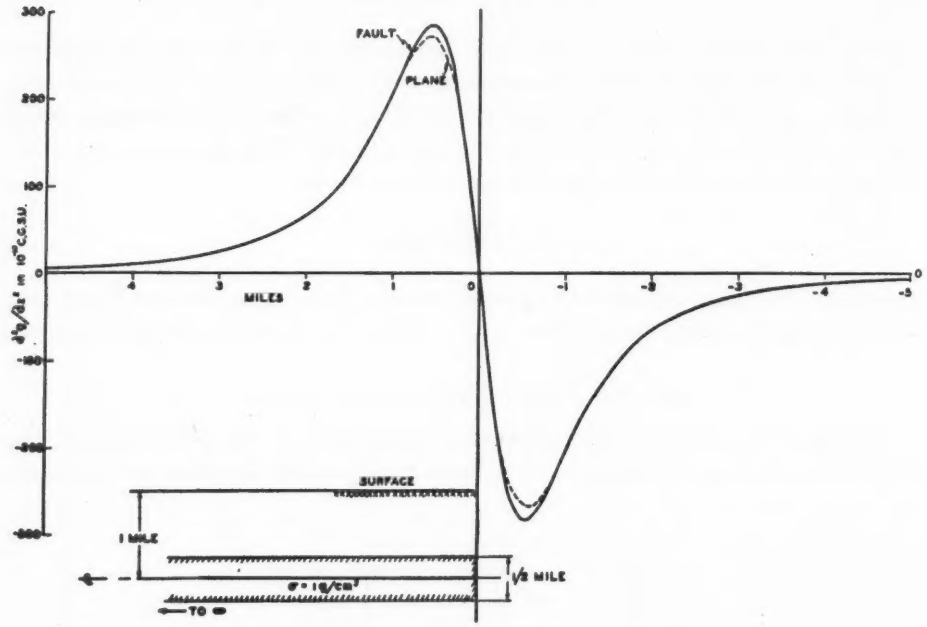

FIG. 9. Second derivative for a vertical fault and a semi-infinite horizontal plane through the center of the fault and of the same mass per unit area.

but the above formulas are useful for "thin" vertical faults. This point is discussed in more detail in the next section.

THE VERTICAL FAULT

This is a two-dimensional structure, independent of the y-coordinate. The typical cross section in Figure 10 is for the plane $y=0$. Let the density contrast be σ. By integrating equation (22), we find that the second derivative at O is:

$$\partial^2 g/\partial z^2 = 2\gamma\sigma x_1\left[1/r_1^2 - 1/r_2^2\right]. \qquad (24)$$

Figure 9 shows the second derivative plotted from this formula for the case in which d is 1 mile, t is $\frac{1}{2}$ mile and σ is 1 gram per cubic centimeter.

An obvious way to approximate a vertical fault of throw t and density contrast σ is to condense it on a semi-infinite horizontal plane passing through the center of the fault, with mass per unit area equal to σt. Figure 9 shows

plotted together the second derivative in a particular case both for a vertical fault and for this condensation. Comparison of the two curves indicates that the plane approximation is so close that it is difficult to show the differences graphically except at the peaks. In fact, an analytical study, which because of its length is given in the Appendix, shows that the maximum error in this approximation when the fault thickness is less than or equal to half the depth to center is less than 12 per cent of the true value; when the thickness is less than or equal to one-tenth the depth, this maximum error is less than one-half per cent. The

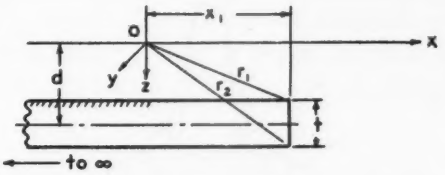

FIG. 10. Notation for study of vertical fault.

plane approximation is thus sufficiently close for practical use when the fault thickness is less than or equal to one-half the central depth.

Since we can manufacture a two-dimensional rectangular block by taking the difference between two vertical faults appropriately placed, we can easily find the second derivative picture for such a block. Similarly we can find the second derivative for any two -dimensional structure bounded by any number of horizontal and vertical surfaces. This can be done graphically or the required formula can be written down almost immediately from equation (24).

As an example, the second derivative for a set of rectangular blocks of the same thickness and depth to center but with different lengths has been found graphically and is shown in Figure 11. A study of these curves indicates that for the longer blocks the position of the ends is approximately given by the reversals in sign. Again, the ratio of the minimum value to the maximum value increases with the length over the range of lengths considered. Thus the elements of the longer blocks can be determined, at least approximately, when the density contrast is known and the thickness is less than half the depth, by comparison with the curves of Figure 11.

ACCURACY OF SECOND DERIVATIVE INTERPRETATION

Since second derivative values found either graphically or by coefficients are necessarily approximate, the question arises as to the accuracy of structural interpretations deduced by the methods suggested in the preceding sections. A structure parameter based on a peak magnitude may not be reliable, for example, when a coefficient set is used which cuts down peak values, as the sets tested in Figure 6. However, this figure indicates that the position of reversals in sign is preserved fairly well and the same greater relative accuracy might be

expected in the graphical method for zero or near zero slopes, since the relative change in the tangent due to a small error $\Delta\theta$ will be least for a zero slope (because $[\tan(\theta_0+\Delta\theta)-\tan\theta_0]/\Delta\theta=\sec^2\theta_0$, to a close approximation; compare in this connection the average value curves in Figures 2 and 3). Since the depth for certain of the structures considered above can be determined from the reversal position, this is a matter of practical importance.

As a test of this the depths for the sphere and cylinder previously described,

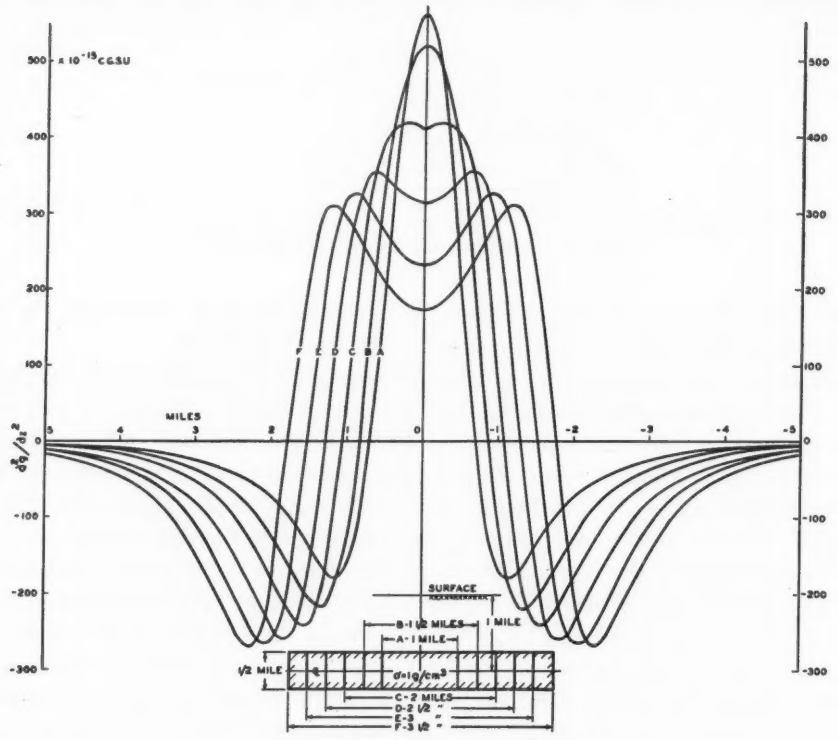

FIG. 11. Second derivative for rectangular blocks.

with maximum gravity 1.5 milligals and depth to center of 15,000 feet, were computed from the reversal distance using second derivative values found by the graphical method. At the scale used, 1 inch = 4,000 varas (1 vara = 33.3 inches), the true depth z was 3.429 cm. The computed depths are given in the following table:

	Computed depth	*Error*
Sphere—g correct to 0.1 mg.	3.7 cm.	9%
Sphere—g correct to 0.01 mg.	3.7 cm.	9%
Cylinder—g correct to 0.1 mg.	3.5 cm.	3%
Cylinder—g correct to 0.01 mg.	3.6 cm.	6%

These values show that the results are sufficiently accurate for practical purposes. With field data the errors will presumably be greater.

SECOND DERIVATIVE PICTURES FOR SOME OIL FIELDS

We now present the second derivative pictures of some typical oil fields. These have been selected especially to show the greater resolution obtainable with the second derivative than with gravity. In all cases the second derivative calculations were made using equation (15). The gravity pictures are for the Bouguer anomaly and are based on gravimeter surveys.

The unit for the second derivative on these maps is 10^{-15} times the c.g.s. unit and has been found to result in numbers of convenient size. Moreover, it fits in neatly with the sequence of powers already adopted for practical prospecting use. For gravity the milligal (10^{-3} c.g.s.u.) is standard as is the Eötvös unit (10^{-9} c.g.s.u.) for the vertical gradient. If the second derivative unit is taken as 10^{-15} c.g.s.u., there is then a factor of 10^{-6} in the progression of the derivatives.

The Mykawa Gravity Minimum, Texas Gulf Coast

The observed gravity picture for the Mykawa-Friendswood-Hastings-Manvel area, Texas, shown in Figure 12, is dominated by a large minimum, commonly

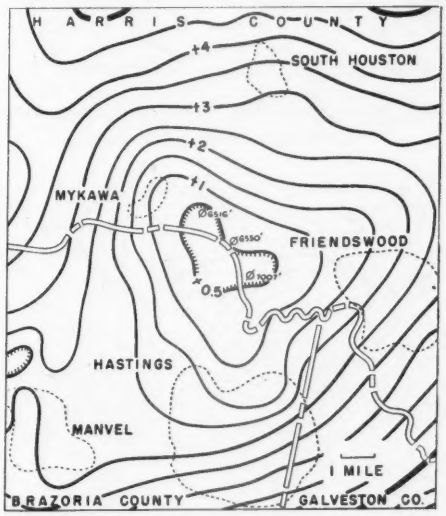

FIG. 12. Mykawa gravity minimum, Texas Gulf Coast. Observed gravity. Contour interval, 0.5 milligal.

referred to as the Mykawa gravity minimum, which is the sum of the effects of the four salt domes. Its appearance is indeed deceptive; in fact, a number of deep dry holes were drilled in unsuccessfully testing the central minimum area.

Even the residual gravity picture, shown in Figure 13, would be misleading if interpreted as a single feature; the Manvel dome is the only one which is clearly resolved. However, the second derivative, made with a grid of mile spacing and shown in Figure 14, resolves the four domes clearly and accurately. Further, there is no longer a deceptive central minimum.

The Los Angeles Basin, California (Hammer, 1950)

Figure 15 shows the gravity for a portion of the Los Angeles basin in Cali-

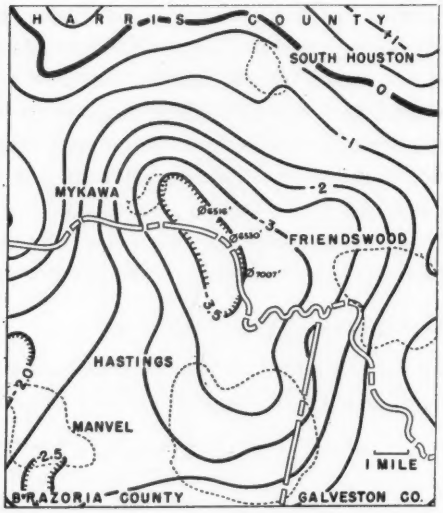

FIG. 13. Mykawa gravity minimum, Texas Gulf Coast. Residual gravity. Contour interval, 0.5 milligal.

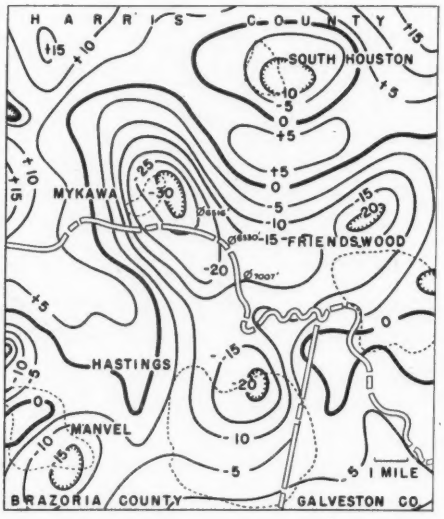

FIG. 14. Mykawa gravity minimum, Texas Gulf Coast. Second derivative. Contour interval, 5×10^{-15} c.g.s.u.

fornia. The gravimeter station locations are marked by crosses. Outlined are the known oil fields which certainly are not obvious in the gravity picture. But

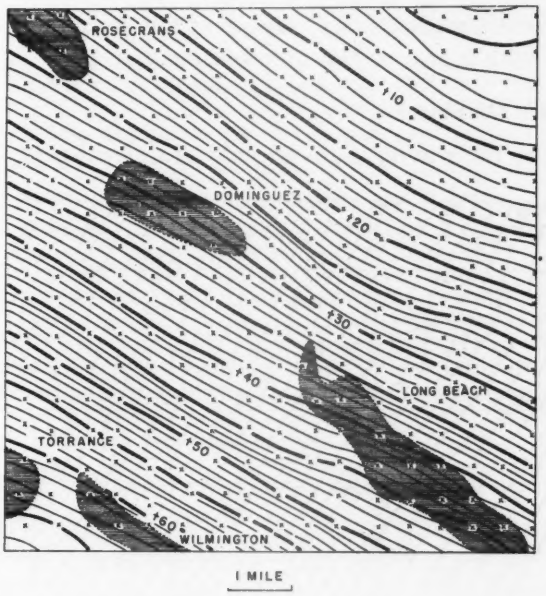

FIG. 15. Los Angeles basin, California. Observed gravity. Contour interval, 1 milligal. (By permission of Colorado School of Mines)

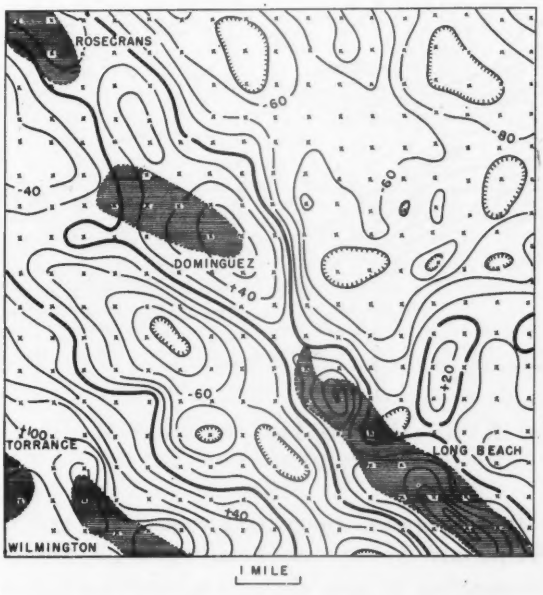

FIG. 16. Los Angeles basin, California. Second derivative. Contour interval, 20×10^{-15} c.g.s.u. (By permission of Colorado School of Mines)

these fields are seen immediately as "highs" in the second derivative picture of Figure 16, made with a grid of half-mile spacing.

The Cement Field, Oklahoma

Figure 17 shows the gravity in the vicinity of Cement field, T5-6N, R8-10W,

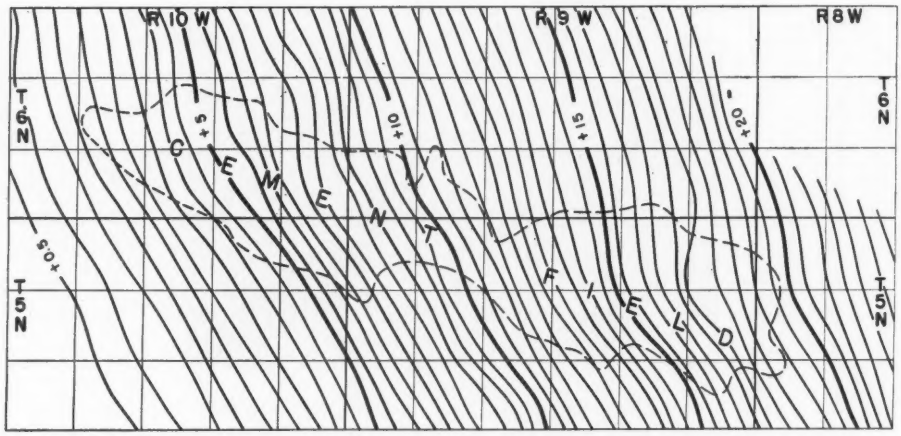

FIG. 17. Cement field, Oklahoma. Observed gravity. Contour interval, 0.5 milligal.

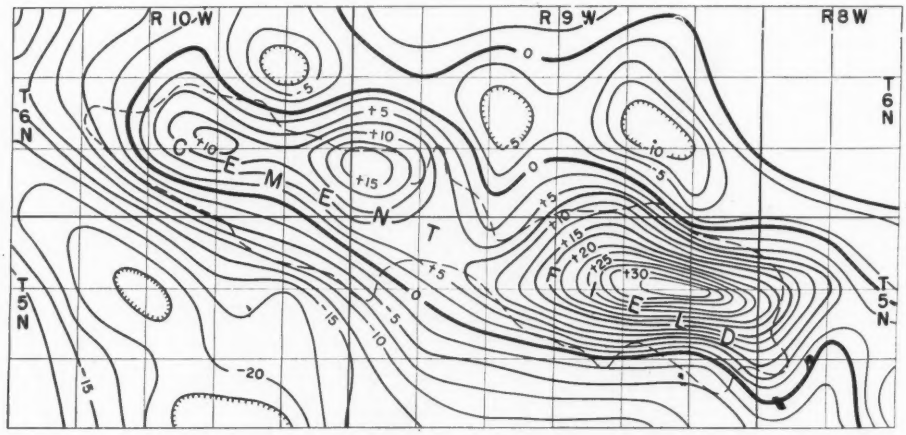

FIG. 18. Cement field, Oklahoma. Second derivative. Contour interval, 2.5×10^{-15} c.g.s.u.

Oklahoma. The strong regional completely masks the gravity picture of the field, which shows plainly on the second derivative picture of Figure 18, made with a grid of mile spacing. In fact, the zero second derivative contour matches quite well the outline shown for the field.

These examples well illustrate the high resolving power of the second deriva-

tive method when it is used on gravity surveys of sufficiently close spacing and high accuracy.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the cooperation and aid received in the carrying out of the work described from many past and present members of the Gravity Interpretation Section of the Gulf Research & Development Company. When this work was started, the writer was a member of this Section, which was under the direction of Dr. L. L. Nettleton; at present it is headed by Dr. Sigmund Hammer; to both the writer owes much in encouragement and assistance. The figures were prepared by Robert D. Craighead and Robert J. Gille. The writer also wishes to thank Dr. Paul D. Foote, Executive Vice President, Gulf Research & Development Company, for permission to publish this paper.

APPENDIX

The Accuracy of the Plane Approximation to the Vertical Fault

In this Appendix we shall study the error introduced when the second derivative effect due to a vertical fault of thickness t, density contrast σ, and depth d to its central plane, is approximated by that due to a semi-infinite horizontal plane of depth d and mass per unit area $t\sigma$.

Let R denote the ratio of the approximate to the accurate value. From equations (22) and (24).

$$R = \left[x_1^2 + \left(d - \frac{t}{2}\right)^2\right]\left[x_1^2 + \left(d + \frac{t}{2}\right)^2\right]/(x_1^2 + d^2)^2. \qquad (25)$$

We set $dR/dx = 0$ and find the values of x_1 for possible maxima or minima to be 0 and $\pm 0.5\sqrt{12d^2 - t^2} = \pm S$.

$$\text{For } x_1 = 0, \qquad R = \left(1 - \frac{t^2}{4d^2}\right)^2 = R_1.$$

$$\text{For } x_1 = \pm S, \quad R = 1 \Big/ \left(1 - \frac{t^2}{16d^2}\right) = R_2.$$

A graph will show that R_2 is the maximum value. R_1 is the minimum value, if we agree to accept the value for $x_1 = 0$ of equation (25) as the evaluation of an indeterminate form, 0/0, since both the approximate and the accurate formulas are zero when $x_1 = 0$. Otherwise, R_1 is the lower bound, which does not affect any of the subsequent reasoning essentially.

The values of x_1 for which the approximate and accurate formulas are equal are found by setting $R = 1$. They are $x_1 = \pm\sqrt{d^2 - t^2/8} = \pm K$. When $|x_1| < K$, $R < 1$; when $|x_1| > K$, $R \geqq 1$. From these equations we see that R does not become greater than R_2 or less than R_1.

The expressions for R_1 and R_2 yield simple limits of error. Thus for $(t/d) \leqq \frac{1}{2}$,

$R_1 > 0.88$ and $R_2 < 1.02$. Therefore, for the case in which the fault thickness is less than or equal to half the depth to center, the maximum error is less than 12 per cent. For $(t/d) \leqq 1/10$, $R_1 > 0.995$, and $R_2 < 1.001$. For this case the maximum error is less than one-half per cent.

The second derivative curves for both a vertical fault and its approximation in the case $t/d = 0.5$ are plotted in Figure 9. The curves confirm the analysis above to the extent that it is possible to indicate such small differences graphically within the scale limitations.

BIBLIOGRAPHY

Hammer, Sigmund, "Recent Developments in Gravity Prospecting," *Quarterly of the Colorado School of Mines*, 45, No. 4A (October 1950) 87–103. See Figures 8 and 9.

Peters, Leo J., "The Direct Approach to Magnetic Interpretation and Its Practical Application," *Geophysics*, XIV (1949) 290–320.

COMBINED ANALYSIS OF GRAVITY AND MAGNETIC ANOMALIES*

G. D. GARLAND†

ABSTRACT

The relationship betwen gravity and magnetic anomalies is investigated. It is shown that the ratio of the anomalous susceptibility to the anomalous density of an unknown body may be determined from gravimeter and vertical magnetometer observations, independent of assumptions as to the depth or form of the body. The use of this ratio in identifying the rock material of the body is discussed, and illustrated by applying the method to a well-known case.

INTRODUCTION

It has been shown (Koenigsberger 1927, Brant, 1948, and Gassmann 1948) that the fundamentals of many of the methods of geophysical exploration, exclusive of the seismic, are similar, in that the secondary effect produced by an anomalous body in a natural or artificial field of force, whether it be a gravitational, magnetic, electric or thermal field, depends on a potential factor. The latter is determined by the form of the body, and its distance from the point of observation. Actually, two potential factors are involved, the gravitational or Newtonian potential in the case of gravitation, and the dipolar potential for magnetic, electric or thermal effects. However, a simple relation connects the two potentials for a given body.

The fact that the interpretation of anomalies in any of the potential fields is fundamentally incapable of a unique solution has also been emphasized (Nettleton, 1940, Skeels, 1947, and 1949). For any given anomaly there is in reality a double infinity of possible solutions. First, the anomalous property of the unknown body is given only by certain limits, and secondly, for any particular property value, there remains an infinite number of forms and positions which the body could have. The purpose of the present paper is to investigate the first problem, that is, the determination of anomalous property values from combinations of potential field methods.

Very briefly, the method which suggests itself is this. The anomaly produced by a body in a field of forces is a function of the corresponding property of the material of the body, and of the potential factor determined by the form of the body. If the anomalies produced by the same body in two different force fields are measured, the unknown potential factor may be eliminated, leaving a relationship between the two different properties. This relationship must hold, independent of the form or position of the unknown body. Just how useful this

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relation may be in determining the rock type of the structure depends on the properties involved and the extent of knowledge of these properties for rocks in the region of the survey. It is suggested that in favorable cases an attempt may be made first to identify the material comprising the anomalous body before the individual force field anomalies are analyzed by the usual methods to give information on the form of the body.

The methods most often carried out in conjunction with each other are the gravity and magnetic. A method of analysis of those anomalies which are detected by both gravimeter and magnetometer will be developed and applied to an example taken from the literature of geophysical exploration.

HISTORICAL DEVELOPMENT OF THE PRINCIPLES EMPLOYED

Poisson (1826), in his first memoir of the theory of magnetism, developed the expression for the potential due to a magnetic dipole. If U_P is the magnetic potential at P, M the magnetic moment of the dipole, and i the direction of magnetization, Poisson's relation is

$$U_P = M \frac{\partial}{\partial i}\left[\frac{1}{r}\right] \tag{1}$$

where r is the distance from P to the center of the dipole.

Consider now the potential of a volume element dv of a body uniformly magnetized to intensity I. For this case

$$M = Idv \tag{2}$$

and

$$U_P = Idv \frac{\partial}{\partial i}\left[\frac{1}{r}\right]. \tag{3}$$

The factor $1/r$ is intimately related to the gravitational potential of the volume element at the point P. If V_P is the gravitational potential, ρ the density of the body, which is considered to be uniform, and G the constant of gravitation,

$$V_P = G\rho dv/r \tag{4}$$

so that

$$1/r = V_P/G\rho dv \tag{5}$$

substituting in equation (3)

$$U_P = I/G\rho \frac{\partial}{\partial i}(V_P). \tag{6}$$

Equation (6) holds for each element of volume of the body, and therefore, because of the assumption of uniform properties, for the body as a whole. Since,

in practice the attracting body is surrounded by other material, the quantities U and V will henceforth be considered as anomalous potentials: similarly I and ρ will be the anomalous properties of the body relative to its surroundings.

This relation was utilized by Eötvös (1907) to develop his well-known equations connecting the components of magnetic force with those second derivatives of the gravitational potential which are measured by the torsion balance, namely V_{zz}, V_{yz}, V_{xy}, V_{Δ}. Eötvös gave three equations, suggesting the possibility of so ving for the three components of magnetization of an anomalous body from torsion balance and magnetometer observations. Actually, only two of these equations are independent, so that such a solution is not possible. In the years since Eötvös published his results, very few applications of them to field observations appear to have been made. One example of such an application is the careful study by Haalck (1929) of the Kursk anomalies in Russia. Using the results of a single traverse, he compared torsion balance and magnetometer results to obtain a relationship between the density and susceptibility of the anomalous body. The problem at hand is to derive a relationship between quantities measured by the magnetometer and the gravimeter. It will be shown that in cases where the same structure produces both a gravity and magnetic anomaly, the following studies are possible, before any assumptions are made as to the form or position of the structure:

1. The observed magnetic anomaly field may be compared with calculated fields, in order to test assumptions of uniform magnetization in various directions. As an example, the hypothesis of magnetization by induction in the present field of the Earth may be investigated.

2. In cases where uniform magnetization and properties are indicated, an estimate may be made of the ratio between the anomalous density and the anomalous polarization of the structure. This may be useful in determining the type of rock which constitutes the structure.

3. If the analysis be made on a body whose anomalous density is known, for example from core samples, the effective average susceptibility of the body may be determined. The comparison of values obtained in this way, with susceptibility measurements on samples could be useful, since the latter measurements often show wide variation.

APPLICATION OF POISSON'S EQUATION TO GRAVIMETER OBSERVATIONS

Let us set up a system of axes in which z is vertical, and positive downward. Differentiating both sides of equation (6) with respect to z,

$$\frac{\partial U_P}{\partial z} = I/G\rho \frac{\partial^2}{\partial z \partial i} (V_P) \tag{7}$$

or

$$Z = I/G\rho \frac{\partial}{\partial i} (g) = I/G\rho \cdot g_i \tag{7a}$$

where: Z is the anomaly in the vertical magnetic intensity at P,

g_i is the gradient, in the direction of magnetization of the body, of the anomalous gravity at P.

Suppose the direction of magnetization to be known, and to be defined by azimuthal angle A, and inclination d.

Then

$$g_i = g_z \sin d + g_s \cos d \tag{8}$$

where: g_z is the vertical gradient of the anomalous gravity at P,

g_s is the horizontal gradient, in the azimuth A, of the anomalous gravity, at P.

Finally:

$$Z = I/G\rho[g_z \sin d + g_s \cos d]. \tag{9}$$

The calculation of g_z, the vertical gradient of gravity, from gravity measurements on the surface of the earth, has been discussed in detail by Evjen (1936), and Hofmann (1949). With the aid of templates and a gravity contour map a method of surface integration may be applied to the computation. Similarly, the factor g_s may be readily obtained from the gravity contours, for any desired azimuth A, by either analytical (Kosbahn, 1949, Skeels, 1949), or graphical means.

Equation (9) allows us to calculate the magnetic anomaly field, i.e., to within a constant factor I/ρ, directly from the observed gravity field, for any assumed direction of magnetization of the anomaly-producing structure. Comparison of the general form of this calculated field with the observed magnetic anomalies will indicate the justification of the assumptions regarding the direction of magnetization and the uniformity of properties. If it is found that the computed field agrees in form with the observed field, the factor I/ρ may be determined so as to give the best fit between the two cases. Thus, the ratio between two important physical properties of the anomalous body has been determined, without any direct assumption as to the form or depth of the body having been made. Actually, the assumption has been implied that the form of the body is such that uniform magnetization is possible. Strictly speaking, this is not true if the surface of the body departs from a second order surface, but the error is probably not serious except for extremely highly magnetized structures. Many of the earlier papers (Koenigsberger 1926, Haalck, 1930), on magnetic calculations contain discussions on the magnitude of this effect, but in practically all of the many equations which have been developed for magnetic interpretation it is neglected. The assumption made is therefore not a particular limitation of the analysis given here.

SIGNIFICANCE OF THE FACTOR I/ρ

When the calculation indicated by equation (9) has been completed for a number of points, and the comparison with the observed magnetic contours made, it will be possible to determine whether or not the hypothesis of uniform mag-

netization is tenable. If the result is negative, it is very probable that the anomalous body possesses an irregular distribution of magnetic material, or mass, or both. However, when the agreement between the calculated and observed magnetic anomalies is good, the investigation may be carried further.

Suppose, for example, that the magnetic anomaly suggests magnetization by the earth's field.

In this case $I = kF$

where F = total intensity of earth's field

k = anomalous susceptibility of the body.

In fitting the calculated field to the observed values, the factor k/ρ is thus obtained.

That this property ratio factor may be suggestive of the rock type of the structure is shown by tables of susceptibilities and densities. These properties,

TABLE 1

APPROXIMATE RANGES OF k/ρ FOR VARIOUS ROCK TYPES OCCURRING IN A NON-MAGNETIC COUNTRY ROCK OF DENSITY 2.7

Rock Type	Density	Excess Density	Susceptibility	Range of k/ρ
	gm/cm³	gm/cm³	10^{-6} cgs units	10^{-6} cgs units
Gabbro	3.0	0.3	52– 4,000[a]	170–14,000
Peridotite	3.3	0.6	7,000– 15,000[a]	12,000–25,000
Sulphide Ore (Pyrrhotite)	4.5	1.8	30,000[b]	17,000
Iron Formation (Magnetite)	4.5	1.8	50,000–100,000	28,000–56,000

[a] Puzicha, K. "Die magnetischen Eigenschaften der Eruptivgesteinen." *Zeit. für praktische Geologie, Bd.* 38, pp. 161–176, 1930.

[b] Brant, A. A. "The Present Status of Geophysics in Canada." *Trans. Can. Inst. of Mining and Metallurgy,* Vol. XLV, pp. 45–87, 1942.

especially the susceptibility, are rather variable, but some general limits may be noted. As a concrete example, Table 1 suggests the property relations of a few common rock types occurring in a non-magnetic country rock of average density 2.7 gr/cm³.

These examples, using "average" values from published tables, are merely to illustrate the range which might be expected in the ratio k/ρ. Values of susceptibility are so variable that any general statement is hardly possible. However, in any given area where some knowledge of the magnetic properties of the rocks is available, the quantity k/ρ may suggest the most probable rock causing the anomaly.

It is interesting also to calculate the ratio for some of the values given by Nettleton and Elkins (1944), as a result of their theoretical calculations from the mineral compositions of norms. The authors tabulate density and susceptibility contrasts for several intrusive relationships which yield the ratios shown in Table 2. For an intruded rock of class I or II, these calculations indicate a decrease in

the ratio of k/ρ as the basicity of the intrusive type increases. In other words, the proportionate increase in susceptibility toward the basic end of the scale is less than the corresponding increase in density. However, measured values of susceptibility often indicate a greater increase for the more basic rocks, so that the ratio k/ρ increases toward the basic end of the scale. It must be emphasized that a universally characteristic ratio of properties for a given intrusive relationship could hardly be found. Rather, it is suggested that in a particular area under consideration sufficient property values would be available to allow calculation of the most probable range of k/ρ, for the different intrusive relations to be expected. In this way, a preliminary separation of a series of coincident gravity and magnetic anomalies according to the most probable rock type could be made.

It should not be construed, however, that a knowledge of the ratio k/ρ alone

TABLE 2

VALUES OF k/ρ (IN 10^{-6} CGS UNITS CALCULATED FROM PROPERTIES OF NORMS AS GIVEN BY NETTLETON AND ELKINS). (SEE BIBLIOGRAPHY)

		C.I.P.W. Classification				
		Intrusive Class				
		I	II	III	IV	V
Intruded Class	I	—	12,500[a]	8,300[a]	5,300[a]	4,300[a]
	II	12,500[b]	—	5,600[a]	2,700[a]	2,300[a]
	III	8,300[b]	5,600[b]	—	−835[c]	390[a]
	IV	5,300[b]	2,700[b]	−835[d]	—	1,500[a]
	V	4,300[b]	2,300[b]	390[b]	1,500[b]	—

[a] Both anomalies positive.
[b] Both anomalies negative.
[c] Magnetic anomaly negative.
[d] Gravity anomaly negative.

would permit a direct determination of the rock material, except in certain unusually favorable cases. The method is most effective for areas in which some knowledge of the magnetic and density properties of the various rock types is available. If, then, gravity and magnetic anomalies are encountered, and the property ratio factor is determined, there is a good possibility of eliminating certain rock types as possible causes, and of suggesting the most probable types.

APPLICATION OF THE METHOD TO THE BAUXITE REGION OF ARKANSAS

In order to illustrate the method of analysis outlined above, an example of a prominent gravity and magnetic anomaly has been chosen from the recent literature. The anomaly is one which was presented and discussed by Malamphy and Vallely (1944), in their report on geophysical investigations in the Arkansas bauxite region. A comparison of Figures 1 and 3, which show gravity and magnetic contours taken from maps of these authors, will indicate the similarity between the main magnetic and gravity anomalies. However, the example has been

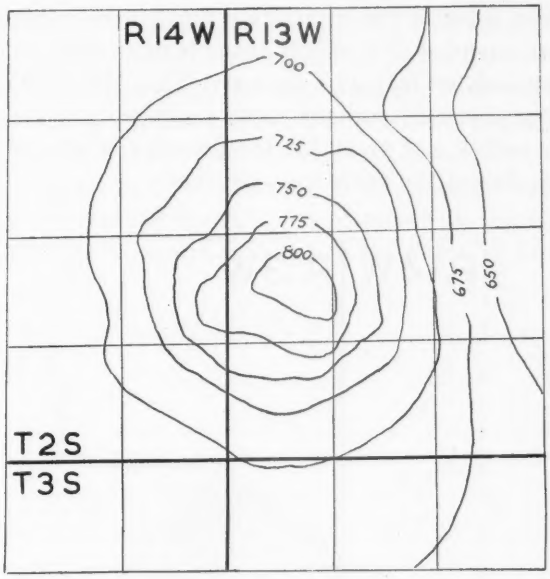

FIG. 1. Gravity anomaly near Bauxite, Arkansas. Gravity anomaly contours at 2.5 milligal interval taken from map of Malamphy and Vallely.

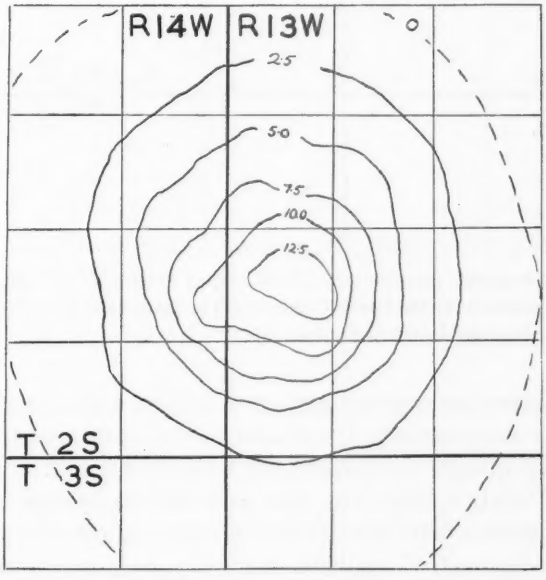

FIG. 2. Contours of residual gravity after applying a regional correction to the area shown in Figure 1. Contour interval 2.5 milligals.

chosen to illustrate some of the difficulties which may be encountered in the process, and is not intended as a perfect example of an isolated gravity anomaly coinciding with an isolated magnetic anomaly. The chief limitations in this case are first a rather pronounced regional trend superimposed on both the gravity and magnetic anomalies, and secondly, the presence of several very local magnetic highs, which distort the main anomaly field.

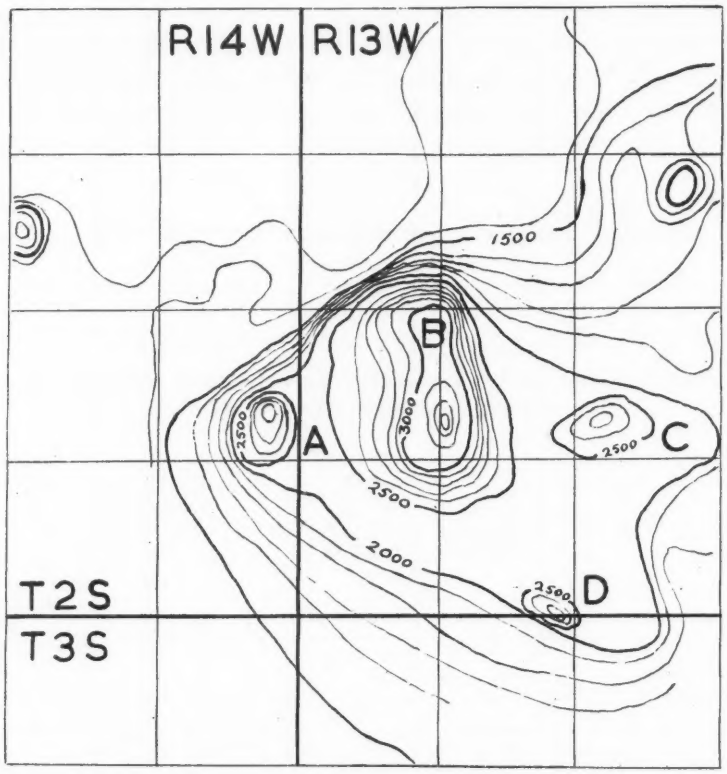

FIG. 3. Magnetic anomaly near Bauxite, Arkansas, as illustrated by Malamphy and Vallely. Contour interval 100 gammas for the fine line contours. The features at *A*, *B*, *C*, and *D*, are assumed to be local highs superimposed on the main anomaly.

Figure 2 indicates the residual gravity obtained after correcting for the regional decrease to the eastward. It should be mentioned that the exact regional effect is somewhat difficult to estimate, since the area is located near the edge of Malamphy and Vallely's map. The magnetic field to be expected due to magnetization in the earth's field was calculated from the gravity anomaly by using a chart to obtain the vertical gradient of gravity, and measuring the horizontal gradient graphically. The resultant magnetic anomaly, in terms of the factor I/ρ, is shown in Figure 4. Because of uncertainties in the exact extent of the residual

gravity anomaly, the outer boundary of the calculated magnetic anomaly, and also the area of negative anomaly to be expected on the northern side, are rather indefinite. The comparison between the calculated and observed magnetic anomalies is shown by profiles in Figures 5 and 6. If one removes the more local magnetic effects at *A*, *B*, *C*, and *D*, the fit between the calculated and observed profiles is fairly good. This suggests that the main magnetic anomaly could be caused by a body of relatively uniform susceptibility, magnetized by the earth's field.

To fit the calculated magnetic anomaly to the observed anomaly requires a

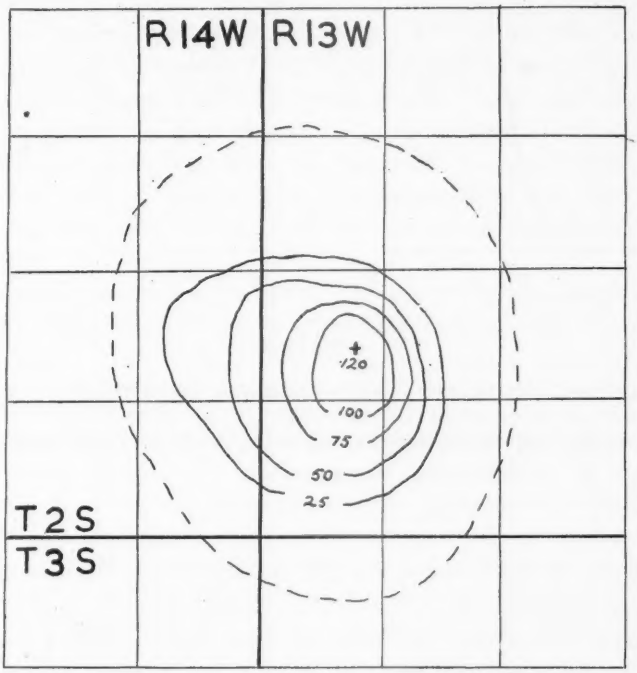

FIG. 4. Magnetic anomaly calculated from the gravity anomaly, on the assumption of magnetization in the direction of the earth's field. Contour of the gradient g_i in Eötvös units. Vertical magnetic anomaly $z=(g_i)(I/G_\rho)(10^{-9})$. The formula gives the vertical magnetic anomaly in gauss, when the property factor k/ρ and the gravitational constant G are expressed in cgs units.

value of I/ρ of $9{,}500\times10^{-6}$ cgs units. On the assumption of magnetization by the earth's field, this is equivalent to a value of k/ρ of $15{,}000\times10^{-6}$ cgs units. Referring to the table of properties of rocks of the district given by Malamphy and Vallely, a "basic igneous rock" from nearby Granite Mountain is quoted as having a density of 3.06 and a susceptibility of $8{,}514\times10^{-6}$ cgs units. Assuming that such a rock is intruded into the non-magnetic Paleozoic rocks of the area, whose average density is 2.60, the value of k/ρ to be expected is about $18{,}000\times10^{-6}$ cgs. Thus, the rock material producing the anomaly studied could well

be a basic rock of similar magnetic and density properties to the known basic rocks of the area. This is suggested by Malamphy and Vallely, so the quantitative study bears out their interpretation.

The above example illustrates how information on the properties of an anomaly-producing body may be obtained by a comparison of gravity and magnetic anomalies.

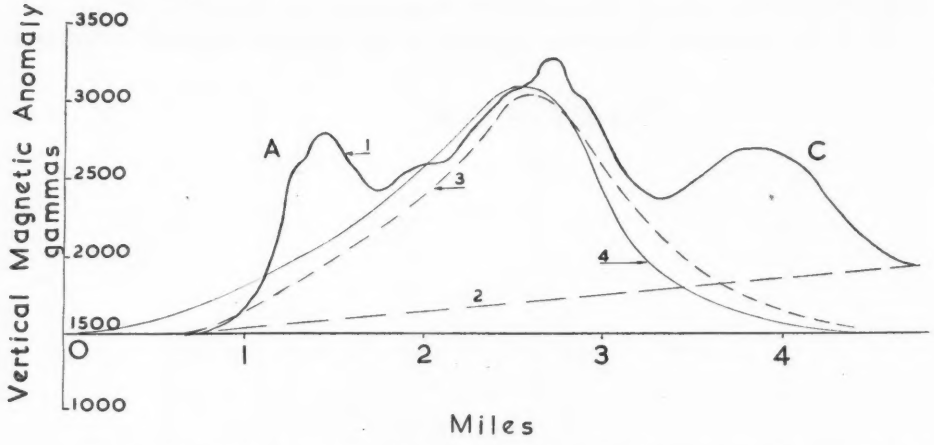

FIG. 5. Comparison of observed and calculated magnetic profiles along an east-west section through the peak of the main magnetic anomaly. (1) observed profile; (2) regional increase in magnetic anomaly; (3) observed profile after correction for regional and local effects; (4) calculated profile.

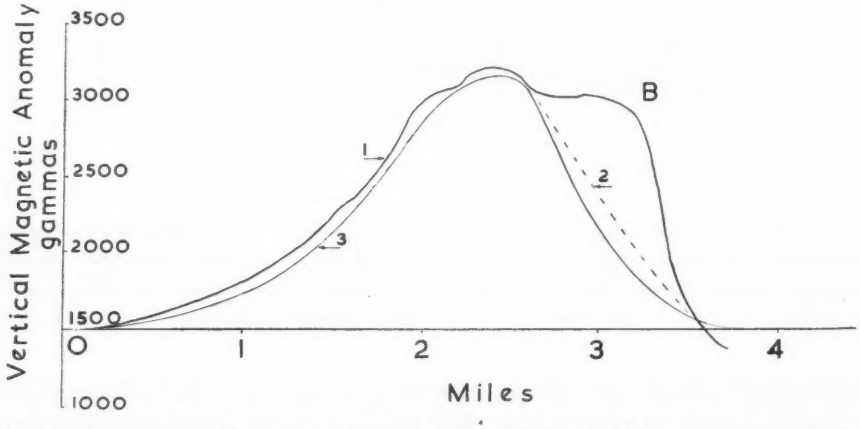

FIG. 6. Comparison of observed and calculated magnetic profiles along a north-south section through the peak of the main magnetic anomaly. (1) observed profile; (2) removal of local effect at *B*; (3) calculated profile.

CONCLUSIONS

A method of analyzing the results of combined gravity and magnetic surveys has been developed which provides information on the properties of anomalous bodies. The method is based on the equation of Poisson, and is closely allied to

the work of Eötvös and Haalck on the relation between torsion balance and magnetometer observations. However, there is no record of either of these workers using the property ratio factor, I/ρ or k/ρ, as a diagnostic feature for unknown structures.

Certain basic assumptions must be made before the analysis is possible. These have been mentioned above, but are summarized here:

1. The same structure or body is responsible for both the magnetic and gravity anomalies.
2. The body has uniform properties and is uniformly magnetized, i.e. demagnetization effects may be neglected. This assumption can be verified to an extent, if the general form of the calculated magnetic anomaly field agrees with the form of the observed anomaly. That is, any great irregularities in properties will probably result in complete failure to match the two fields. In such cases, of course, the method is not applicable.
3. The most probable direction of magnetization is indicated by the best agreement between the forms of the calculated and observed magnetic anomalies.
4. The regional anomalies, including the effects of neighboring bodies, for both the gravity and magnetic cases have been adequately removed.
5. The method employed for obtaining the horizontal and vertical gradients of gravity is sufficiently accurate.

All of the assumptions place limitations on the procedure. However, it is felt that the ability to obtain some knowledge of the properties of the anomalous body, independent of deductions as to its form or depth, is a valuable result of the combined measurements.

It was mentioned in the Introduction that besides the gravitational and magnetic methods of geophysical exploration, electrical and thermal methods are in the potential field group. That is, the anomalous voltage distribution due to a body in a uniform electric field, and the anomalous temperature distribution produced by a body in a field of uniform heat flow, both depend on a potential factor. This factor may be calculated from the gravitational potential for given directions of the electric or thermal fields. Thus, if a structure produces a measurable anomaly in more than one of the four fields, a combination of the measurements may be used to find the ratios of the corresponding property contrasts, i.e., density, magnetic polarization, electric polarization or thermal conductivity. Of course, the individual values are not uniquely determined, even if all possible ratios are known. It would appear that, theoretically at least, the only parameter of an unknown body which is determinable without ambiguity from potential field anomalies is a ratio of property contrasts, and this only when a combination of methods is used.

BIBLIOGRAPHY

Brant, A. A. "Some Limiting Factors and Problems of Mining Geophysics," *Geophysics*, XIII (1948) 556–581.

Eötvös, R. von. "Bestimmung der Gradienten der Schwerkraft und ihrer Niveauflächen mit Hülfe der Drehwage," *Abhandlungen der XV allgemeinen Konferenz der Erdmessung in Budapest*, 1906. I (1907) 59.

Evjen, H. M. "The Place of the Vertical Gradient in Gravitational Interpretation," *Geophysics*, I (1936) 127–136.

Gassmann, F. "Auswertung geophysikalischer Sondierungen mit Hilfe von Potentialfeldern," *Schweizerische Mineralogische und Petrographische Mitteilungen*, XXVIII (1948) 335–352.

Haalck, H. "Zur Frage der Erklärung der Kursker magnetischen und gravimetrischen Anomalie," *Beiträge zur Geophysik*, XXII (1929) 241–255.

———. "Die magnetischen Methoden der angewandten Geophysik," *Handbuch der Experimentalphysik* (Wien-Harms), XXV, 3 (1930) 323–324.

Hofmann, W. "Ueber Anwendungen einer Formel zur Berechnung des Vertikal-Gradients der Schwere," *Geofisica Pura e Applicata*, XIV (1949) 145–162.

Koenigsberger, J. "Veränderung des Erdfeldes durch Einlagerungen von abnormaler Suszeptibilität in Erdkruste," *Zeitschrift für Geophysik*, II (1926) 169–171.

———. "Über die Berechnung der Wirkungen von Einlagerungen auf natürliche und künstliche homogene Felder in der Erde," *Beiträge zur Geophysik*, XVIII (1927) 115–126.

Kosbahn, B. "Über die Berechnung sämtlicher Feldgrössen aus der Vertikalintensität und deren Anwendung auf die Auswertung von Schwerebildern," *Geofisica Pura e Applicata*, XV (1949) 27–38.

Malamphy, Mark C., and Valleley, James L. "Geophysical Survey of the Arkansas Bauxite Region," *Geophysics*, IX (1944) 324–366.

Nettleton, L. L. *Geophysical Prospecting for Oil*, McGraw-Hill (1940) pp. 101–102 and 205–206.

———, and Elkins, T. A. "Association of Magnetic and Density Contrasts with Igneous Rock Classifications," *Geophysics*, IX (1944) 60–78.

Poisson, S. D. "Mémoire sur la Théorie du Magnétisme," *Mémoires de l'Académie royale des Sciences de l'Institut de France*, V (1826) 247–338.

Skeels, D. C. "Ambiguity in Gravity Interpretation," *Geophysics*, XII (1947) 43–56.

———, and Watson, R. J. "Derivation of Magnetic and Gravitational Quantities by Surface Integration," *Geophysics*, XIV (1949) 133–150.

DISPERSION IN SEISMIC SURFACE WAVES*

MILTON B. DOBRIN†

ABSTRACT

A non-mathematical summary is presented of the published theories and observations on dispersion, i.e., variation of velocity with frequency, in surface waves from earthquakes and in water-borne waves from shallow-water explosions. Two further instances are cited in which dispersion theory has been used in analyzing seismic data.

In the seismic refraction survey of Bikini Atoll, information on the first 400 feet of sediments below the lagoon bottom could not be obtained from ground wave first arrival times because shot-detector distances were too great. Dispersion in the water waves, however, gave data on speed variations in the bottom sediments which made possible inferences on the recent geological history of the atoll.

Recent systematic observations on ground roll from explosions in shot holes have shown dispersion in the surface waves which is similar in many ways to that observed in Rayleigh waves from distant earthquakes. Classical wave theory attributes Rayleigh wave dispersion to the modification of the waves by a surface layer. In the case of earthquakes, this layer is the earth's crust. In the case of waves from shot-holes, it is the low-speed weathered zone. A comparison of observed ground roll dispersion with theory shows qualitative agreement, but it brings out discrepancies attributable to the fact that neither the theory for liquids nor for conventional solids applies exactly to unconsolidated near-surface rocks. Additional experimental and theoretical study of this type of surface wave dispersion may provide useful information on the properties of the surface zone and add to our knowledge of the mechanism by which ground roll is generated in seismic shooting.

INTRODUCTION

The geophysicist engaged in seismic prospecting ordinarily looks upon surface waves as a perverse creation designed to interfere with his reflections. He adjusts his equipment and field procedure to eliminate them from his records. In most cases he succeeds very well in suppressing them while capturing the compressional waves that he wants. Occasionally, however, the surface waves cannot be removed by standard methods and in such areas the seismic method often turns out to be unusable. When this occurs he often wishes that more fundamental information were available to him as to how these waves are generated and propagated.

The earthquake seismologist, on the other hand, tries to make use of the waves on his records and often designs his equipment so as to observe them most fully. For well over a half a century, mathematical physicists such as Rayleigh, Love, Lamb, Jeffreys and Stoneley have investigated the theory of surface waves and have established a theoretical basis for the principal types observed on earthquake records. Their work has made it possible for seismologists to obtain valuable information from such waves on the nature and thickness of the earth's crust. The techniques that have been developed for this purpose have more recently been adapted to study elastic wave transmission through shallow water,

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a subject of considerable current interest to geophysicists concerned with offshore prospecting.

The usefulness of surface waves in studying subsurface structure lies in the fact that they exhibit a variation of velocity with wave length when there are elastic or density discontinuities at depths below the surface roughly of the same order of magnitude as the wave length. This variation, known as dispersion, is observable on seismic records as a change in the period of successive wave cycles with time. Its nature depends on the depth of the discontinuity and the elastic constants of the material above and below it. Long surface waves such as those recorded from earthquakes exhibit dispersion because of the discontinuity in the earth's superficial layers. Shorter compressional waves travelling through shallow water are dispersive because of the discontinuity at the water bottom. By the same token one might expect the weathered layer to cause dispersion in the Raleigh waves obtained as "ground roll" in seismic prospecting. This, as will be shown later, is also observed.

BASIC CONCEPTS

Although the technique of studying the subsurface using the dispersion characteristics of surface waves has been employed for more than a quarter of a cen-

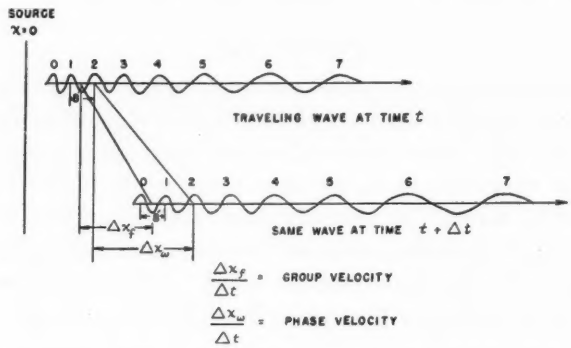
SOURCE
x=0
0 1 2 3 4 5 6 7
TRAVELING WAVE AT TIME t
0 1 2 3 4 5 6 7
SAME WAVE AT TIME t + Δt
Δx_f
Δx_ω
Δx_f / Δt = GROUP VELOCITY
Δx_ω / Δt = PHASE VELOCITY

FIG. 1. Group and phase velocities for waves from impulsive disturbance traveling on water surface.

tury, its application to exploration geophysics has been somewhat limited by the fact that much of the important literature on the subject is scattered and not easily accessible in this country. For this reason, there seems to be justification for reviewing the fundamental theory of dispersion, for summarizing the published material in this field, and for pointing out several applications which have not been previously published.

To illustrate some of the fundamental concepts involved, let us consider a very simple example of dispersive wave propagation, the spreading out of a gravity water wave from a concentrated impulsive disturbance of the water surface.

The initial displacement here is considered to be instantaneous and to contain Fourier components at all frequencies. In this case the speed at which each component travels depends on the wave length, the longer waves traveling faster. Figure 1 shows a cross-section of the water surface shortly after the disturbance as well as another one at a time Δt later. The longest wave lengths are at the head of the train, the shortest at the end. If one follows any individual wave crest he sees that its wave length increases with time. The speed of such a crest, which depends on the wave length, is defined as its *phase velocity*. The observed train of waves results from the interference of all the component sine waves, each traveling at the proper phase velocity for its frequency.

Suppose on the other hand, that we are following the energy having a given wave length. That would travel at a different speed which we call the *group velocity*, U. The group velocity, like the phase velocity, is a function of wave length and it is related to the phase velocity, C by the equation:

$$U = C - \lambda \, (dC)/(d\lambda)$$

where λ is the wave length. On a record of disturbance versus time, at a known distance from the source, the group velocity of any wave crest is simply the distance traveled divided by the time between the instant of initial disturbance and the arrival of the crest. The phase velocity, on the other hand, could be obtained from the slope of a time-distance curve for the same crest based on observations at a number of closely spaced positions.

Because of space limitations, it is not possible to discuss the mathematical theory of dispersive wave propagation here. A mechanism for such propagation can be shown qualitatively, however, in Figure 2 for the case of a compressional wave in a water layer. The ray shown is reflected multiply at an angle greater than the critical angle and hence there is no loss of energy into the bottom. The angle of reflection, θ, is such that wave fronts corresponding to successively reflected rays are all in phase, and the resultant wave travels obliquely through the layer with a horizontal velocity of $V_1/\sin\theta$. This velocity is the phase velocity. It will be greater than the velocity of sound in water and less than the velocity in the substratum because the angle θ must always be larger than the critical angle. Waves reflected at angles other than those giving phase reinforcement of this kind cancel because of destructive interference. The angle for reinforcement depends on frequency. The elastic constants of the bottom also influence it through the phase change on reflection. Hence the phase velocity depends on frequency, and there is dispersive propagation through the water layer.

DISPERSION OF SURFACE WAVES FROM EARTHQUAKES

The earliest theoretical study of dispersive seismic waves was made by Love (1911). Earthquake seismologists had observed that the first high amplitude long-period waves to appear on their records showed horizontal ground motion, perpendicular to the direction of propagation. Love demonstrated mathematically

that these were simply transverse waves confined to a low-speed surface layer, namely, the earth's crust, just as the compressional waves shown in Figure 2 were confined to the water layer. These waves, which have come to be known as Love waves, were shown to have a velocity depending on the wave length, thick-

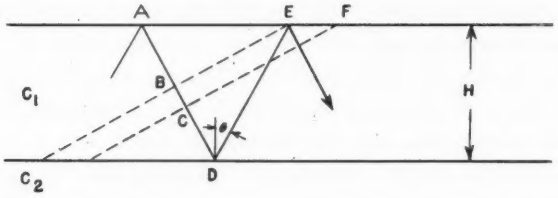

FIG. 2. Ray diagram illustrating normal-made sound transmission in layered medium. Dotted lines represent wave fronts of undamped wave traveling through upper layer, sound velocity C_1, overlying layer with sound velocity C_2 (after Press and Ewing).

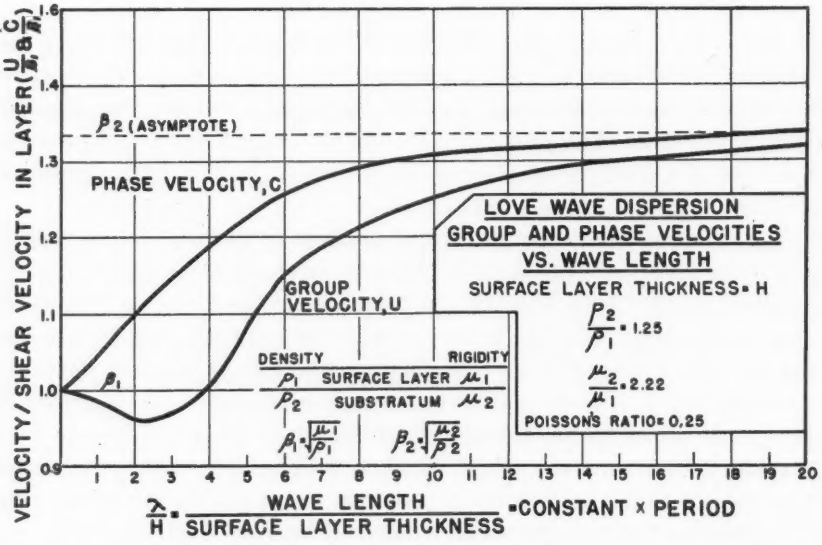

FIG. 3. Dispersion curves for Love waves in the earth's crust. Rigidity and density contrasts between surface layer and substratum are those estimated for earth's crust and subjacent medium.

ness of the crust, and the elastic constants of the crust and the substratum. Figure 3 shows theoretical curves of phase and group velocity versus frequency for Love waves propagated in the earth's crust. The phase velocity for very short wave lengths approaches that of a transverse wave in the upper layer; for very long wave lengths it approaches the transverse speed in the lower layer. The group velocity curve, obtained by graphical differentiation of the phase velocity curve, exhibits a minimum at a wave length about equal to the layer thickness.

More than 65 years ago, Lord Rayleigh (1885) had worked out the theory for

wave propagation along the free surface of a homogeneous solid and had shown that the particle motion at the surface should be retrograde and should have an elliptical orbit in a vertical plane extending radially from the source. The velocity of these waves was shown to be independent of wave length. Waves having this ground motion, now called Rayleigh waves, were subsequently identified in the later portion of the earthquake records, but they came in long trains which suggested a variation of velocity with wave length. Love (1911) showed that

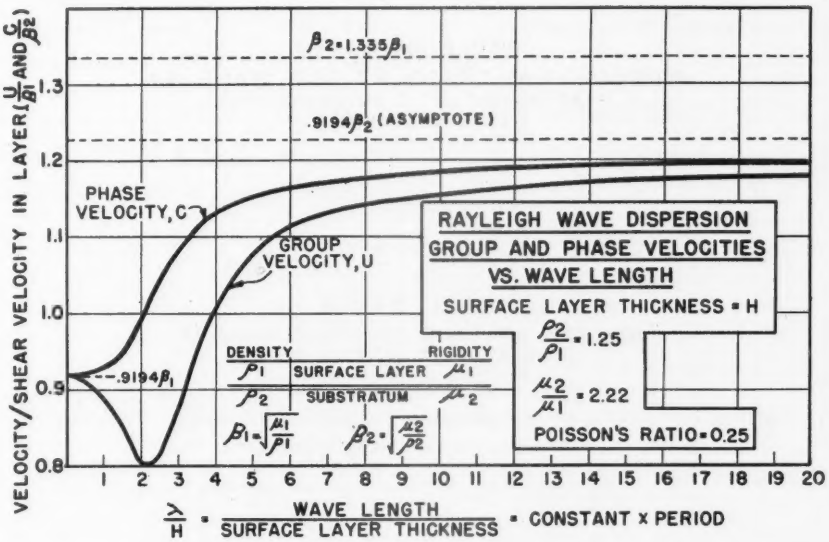

FIG. 4. Dispersion curves for Rayleigh waves in the earth's crust. Rigidity and density contrasts between surface layer and substratum are those estimated for earth's crust and subjacent medium.

Rayleigh waves should be dispersive in the presence of a low-speed surface layer but did not express his results in usable form. Much later, Sezawa (1929) and Jeffreys (1935) worked out theoretical dispersion curves for Rayleigh waves through the earth's crust. Figure 4 shows Jeffreys' curves. The phase velocity approaches Rayleigh wave speed, about 0.92 the transverse speed, for the upper layer at very short wave lengths, and approaches this speed for the substratum at very long wave lengths. This would be expected if one realizes that the shorter waves do not penetrate to the deeper medium at all and the longer waves exist mainly below the surface layer. The group velocity minimum is even more pronounced than for the Love waves.

Figure 5 reproduces traces from actual earthquake records showing Rayleigh and Love wave dispersion. The decrease of period with time on both traces indicates that longer periods travel faster, just as theory predicts. Dispersion curves plotted by Wilson (1948) for two other earthquakes are illustrated in Figure 6. These have the same general form as the group velocity curves previously shown

except that there are no data corresponding to the portion of the theoretical curves in the high frequency region left of the minimum group velocity. Phases corresponding to minimum group velocity have recently been observed and iden-

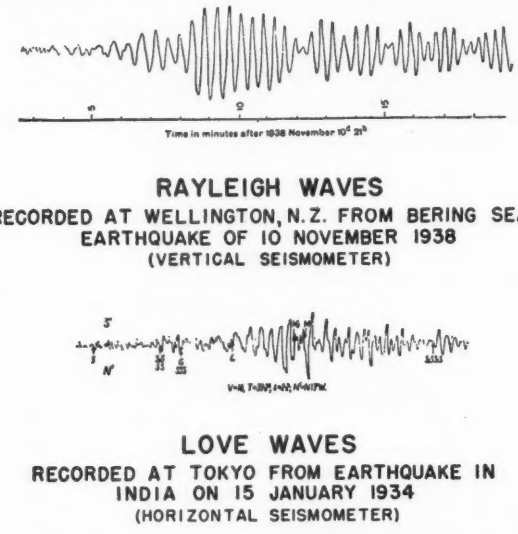

FIG. 5. Earthquake records showing dispersion of Rayleigh and Love waves. Traces reproduced from papers by Bullen and Sezawa.

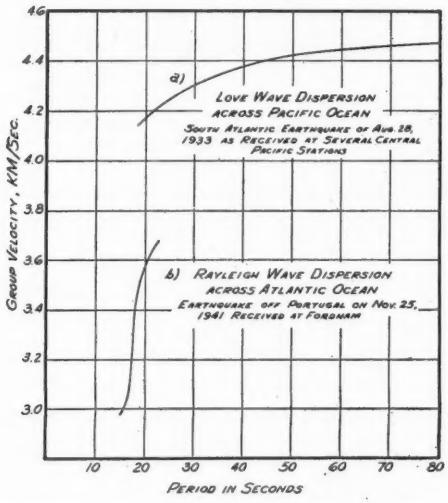

FIG. 6. Dispersion curves plotted from records of two earthquakes (after Wilson).

tified for earthquake waves that have taken paths almost entirely under water.

Gutenberg (1924) first proposed that surface wave dispersion on earthquake records be used to determine the thickness and elastic properties of the earth's

crust. He worked this out for Love waves, obtaining crustal thickness agreeing well with values that had been estimated by other methods. Stoneley (1948) extended this analysis to cover other assumptions, such as a two-layered crust. Jeffreys (1935), Sezawa (1935) and Bullen (1939), subsequently estimated the thickness of the crust from Rayleigh wave dispersion data and concluded that the crust under the Pacific is thinner and considerably different in elastic constants from that under Eurasia. Although this would be expected from isostatic considerations, there is very recent evidence* that the dispersion under the ocean may be attributable to the influence of the water layer over the oceanic part of the crust rather than to any crustal layering.

DISPERSION FROM UNDERWATER EXPLOSIONS

During World War II, Worzel and Ewing (1948) recorded seismic waves from depth charges in shallow water along the East Coast and in the West Indies

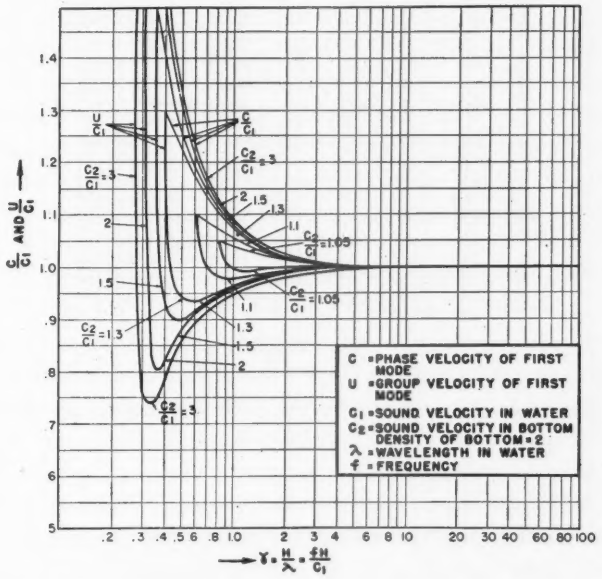
C = PHASE VELOCITY OF FIRST MODE
U = GROUP VELOCITY OF FIRST MODE
C1 = SOUND VELOCITY IN WATER
C2 = SOUND VELOCITY IN BOTTOM DENSITY OF BOTTOM = 2
λ = WAVELENGTH IN WATER
f = FREQUENCY

FIG. 7. Theoretical dispersion curves for waves propagated in water layer over liquid bottom (after Pekeris).

and observed that the pressure wave traveling through the water showed a pronounced dependence of velocity upon period. Here the highest frequencies arrived first, later cycles being progressively longer, just the opposite of the case for earthquake waves. On the basis of their observations, Pekeris (1948) worked

* This comes from a new treatment of dispersion data on Rayleigh waves that have taken suboceanic paths; it is being published by M. Ewing and F. Press in the Bulletin of the Seismological Society of America.

out a theoretical analysis of the water-wave dispersion along the lines that Love had followed in his treatment of the transverse waves propagated in a solid surface layer. Since the bottom consisted in every case of unconsolidated sands he assumed it to have the mechanical properties of a liquid. His theoretical dispersion curves, which gave good agreement with Ewing and Worzel's observations, are reproduced in Figure 7. The upper curves show phase velocity, the lower group velocity, now plotted against frequency instead of period. Each curve is

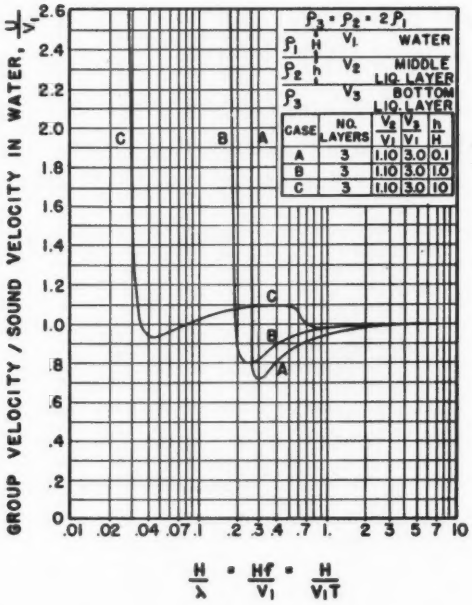

FIG. 8. Theoretical dispersion curves for three liquid layers having characteristics indicated (after Pekeris).

for a different ratio of bottom speed to water speed. The range of ratios is 3 to 1.05. The wave traveling at the minimum group velocity has a high amplitude which makes it quite conspicuous on the record and Pekeris named this the "Airy Wave." For any case where the bottom can be considered liquid the average sound velocity in the bottom down to a maximum of twice the water depth can be determined by plotting the observed dispersion and noting which theoretical curve gives the closest fit.

Pekeris also worked out a number of curves for a three-layered liquid, obtaining results of the type shown in Figure 8. The curves are similar in form to those for the two-layered liquid, except for the one with a very thick middle layer, which has a much lower Airy wave frequency.

Pekeris' treatment has been extended by Press and Ewing (1948a) to cover two additional cases important in shallow water prospecting. One is where the

water is directly underlain by a mud layer with the speed of sound lower than that in water. The second case is when a solid rather than a liquid bottom underlies the water layer (Press and Ewing, 1948b, 1950). The results were used as the basis for the theory that microseisms are transmitted landward from storms at sea as water waves confined to the water layer overlying a solid crust and exhibiting the dispersion corresponding to the solid bottom case.

DISPERSION ON SEISMIC RECORDS MADE AT BIKINI

Let us now consider an example where dispersion theory has been applied to study the submarine geology of an area which has been explored by underwater seismic shooting. This area is Bikini Atoll, where a refraction survey was carried on at the time of the 1946 atomic bomb tests. Here explosion waves from depth charges were received along profiles in the shallow water of the lagoon. The ground-wave arrivals yielded some very interesting information on the deep subsurface structure of the atoll and this has been published (Dobrin, *et al.*, 1949). The minimum shot-detector separations were too long, however, for standard refraction methods to give any data on seismic velocities in the first few hundred feet below the water bottom. Such information was valuable because of the light it might cast on the recent sedimentary history of the atoll. Examination of the water waves on the records showed definite dispersion characteristics and suggested the possibility of applying dispersion theory to the data as a means of investigating the subsurface geology. A complete account of the dispersion study, with emphasis on geological implications, has recently been published in another journal (Dobrin, 1950) from which permission to reproduce Figures 11 to 14 has been obtained.

Figure 9 shows some sample record traces exhibiting water wave dispersion. Note the steady increase in period with time after the first arrival of the water wave. The maximum amplitude and period identify the Airy phase. Figure 10 reproduces some records for much greater shot-detector distances where the water waves are spread out over a longer time. The first two traces show a steady increase in period up to a well defined Airy maximum. The third is for an 18 mile shot-detector distance where all frequencies higher than the Airy frequency have evidently been damped by absorption.

Figure 11 shows shot and receiver locations. The detectors were at fixed positions in shallow water near shore while the shots were along profiles extending across the lagoon over water depths varying as shown by the contours. Records from shots clustered within each of the blocks, bounded by dotted lines, appeared to have very similar dispersion patterns and the velocity-frequency points from all records within such an area were plotted on the same graph. A set of Pekeris' theoretical curves for the two-layer liquid case was superimposed on each plot. Records from the areas marked "A" showed dispersion within the range allowed by liquid bottom theory. Those from the areas designated by "B" were borderline while those from the "C" areas gave group velocities much too high to fit the

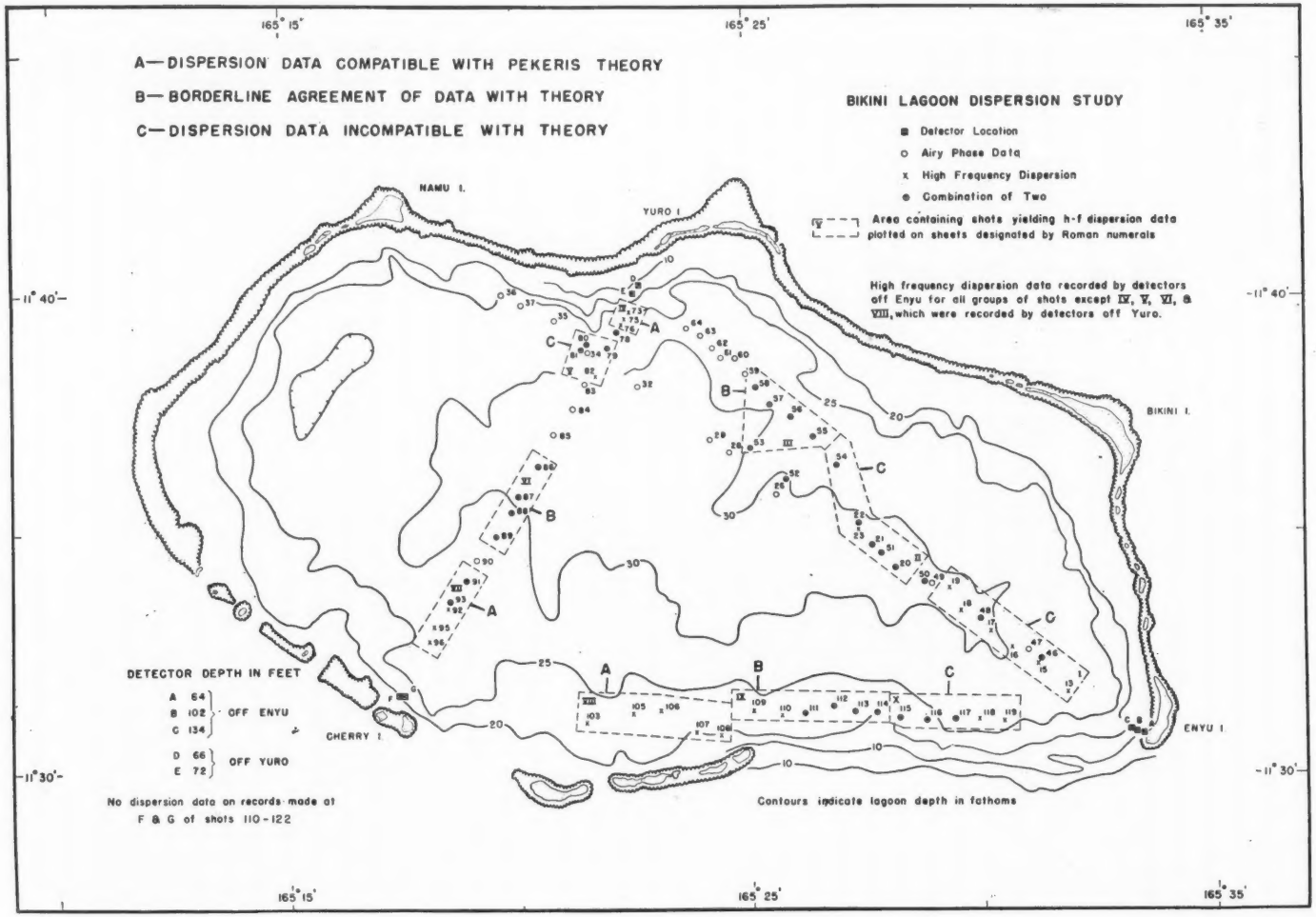
A—DISPERSION DATA COMPATIBLE WITH PEKERIS THEORY
B—BORDERLINE AGREEMENT OF DATA WITH THEORY
C—DISPERSION DATA INCOMPATIBLE WITH THEORY
BIKINI LAGOON DISPERSION STUDY
Detector Location
Airy Phase Data
High Frequency Dispersion
Combination of Two
Area containing shots yielding h-f dispersion data plotted on sheets designated by Roman numerals
High frequency dispersion data recorded by detectors off Enyu for all groups of shots except IV, V, VI, & VIII, which were recorded by detectors off Yuro.
NAMU I.
YURO I.
BIKINI I.
ENYU I.
CHERRY I.
165° 15'
165° 25'
165° 35'
11° 40'
11° 30'
DETECTOR DEPTH IN FEET
A 64
B 102 } OFF ENYU
C 134
D 66 } OFF YURO
E 72
No dispersion data on records made at F & G of shots 110-122
Contours indicate lagoon depth in fathoms

FIG. 9. Map of Bikini Atoll showing location of shot points and detector stations used for the 1946 seismic survey of the lagoon.

liquid bottom theory for any conceivably correct bottom velocity. A representative set of dispersion plots from an area of type "A" is shown by Figure 12. The penetration of the waves into the bottom is expressed as a function of frequency in the upper curves. The data at lower frequencies give information to a much greater depth than do those at the higher frequencies. The distribution of data points when compared with the theoretical curves indicates that for the first 20 feet or so the velocity of sound in the bottom is 1.05 the velocity in water, or 5,250 feet/second, and that the speed increases with depth to about 6,500 feet/second at 80 feet below the bottom. These velocities are not inconsistent with refraction speeds. The liquid nature of the bottom is thus quite well substantiated for the "A" areas.

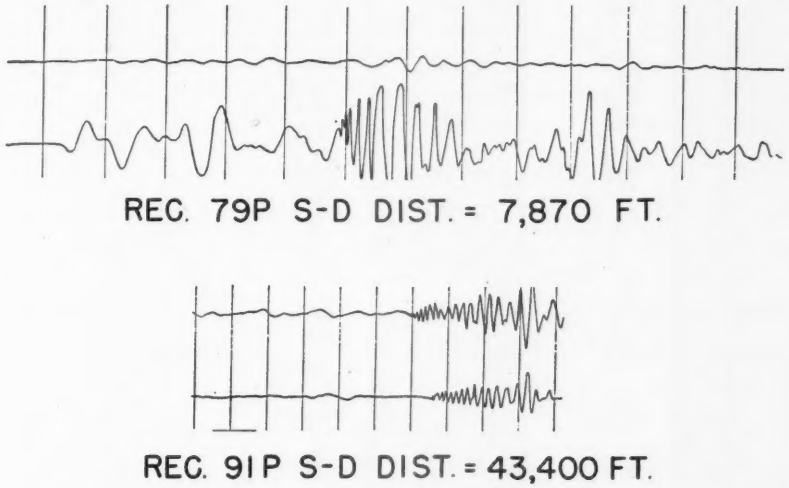

FIG. 10. Bikini record traces showing high frequency water wave dispersion.

A representative plot for a borderline ("B") area, is shown by Figure 13. Here the dispersion data indicated a bottom velocity in the first 20 feet that averages from two to three times the speed in water. This is much higher than appears reasonable from first arrival data and bottom samples. The divergence, however, might be attributable to observational error and no definite conclusions can be drawn from the dispersion results in this type of area.

In the "C" areas, the group velocities were considerably higher than predicted by Pekeris' theory for a simple liquid bottom of any kind, as Figure 14, from such an area, indicates. The data points were compared with theoretical curves based on various other assumptions, such as a solid bottom, two liquid layers below water bottom, or low-speed bottom, but no better agreement could be obtained. Examination of the map shows that the "C" areas cover the deeper parts of the lagoon nearer the center while the "A" areas are in shallow water near the edge of the lagoon. Bottom samples show that the sediments in the deep

FIG. 9. Map of Bikini Atoll showing location of shot points and detector stations used for the 1946 seismic survey of the lagoon.

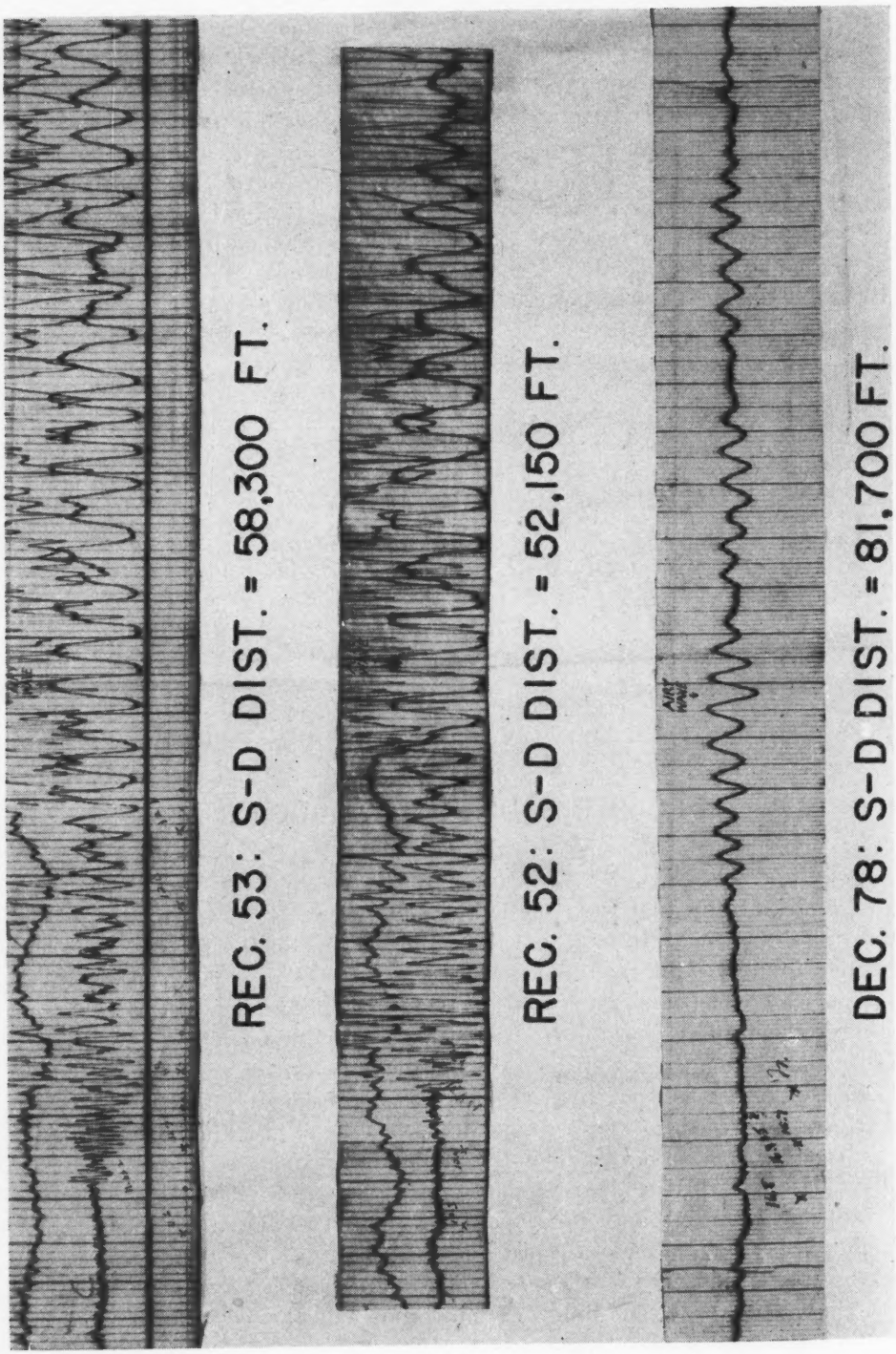

FIG. 11. Bikini record traces showing Airy waves. First two traces show high-frequency dispersion also.

water areas are finer than those in the shallow shelves along the lagoon edge. One would therefore expect a difference in elastic properties between the shallow and deep bottom. It is quite likely that a wave generated over one type of bottom and received over the other would exhibit a dispersion different from that in the laterally homogeneous substratum assumed in the theoretical derivations. If we

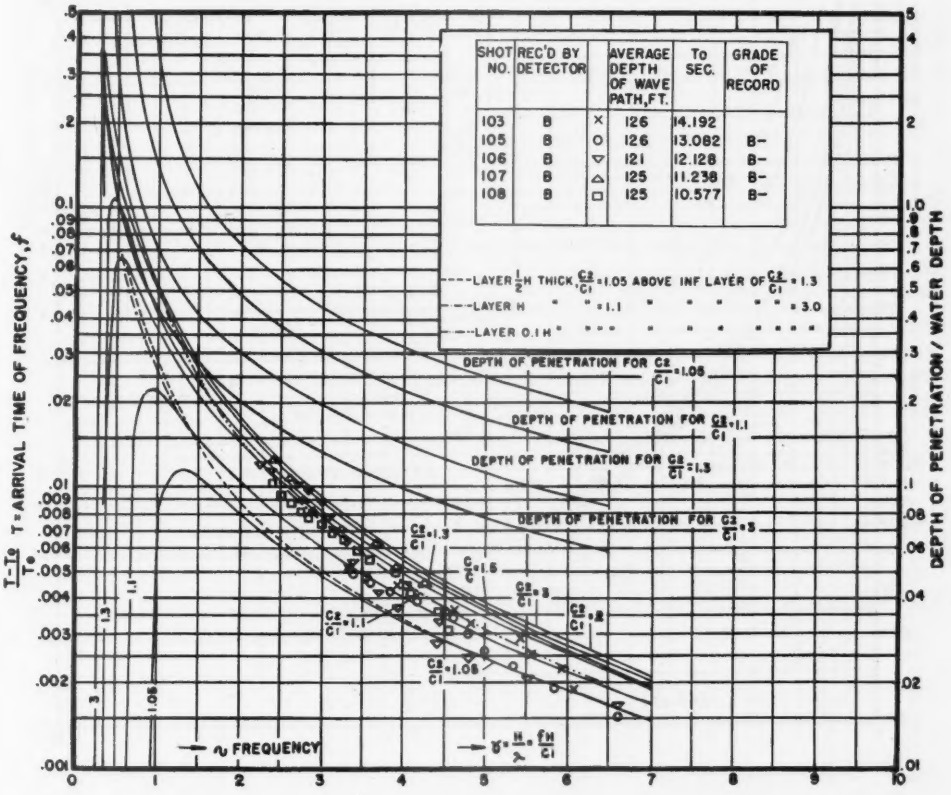
SHOT NO. | REC'D BY DETECTOR | AVERAGE DEPTH OF WAVE PATH, FT. | To SEC. | GRADE OF RECORD
103 | B | × | 126 | 14.192 |
105 | B | ○ | 126 | 13.082 | B-
106 | B | ▽ | 121 | 12.128 | B-
107 | B | △ | 125 | 11.238 | B-
108 | B | □ | 125 | 10.577 | B-
LAYER ½H THICK, Cs/C1 = 1.05 ABOVE INF LAYER OF Cs/C1 = 1.3
LAYER H " " = 1.1 " " " " = 3.0
LAYER 0.1H " " " " " " " "
DEPTH OF PENETRATION FOR Cs/C1 = 1.05
DEPTH OF PENETRATION FOR Cs/C1 = 1.1
DEPTH OF PENETRATION FOR Cs/C1 = 1.3
DEPTH OF PENETRATION FOR Cs/C1 = 3
T = ARRIVAL TIME OF FREQUENCY, f
(T-To)/To
DEPTH OF PENETRATION / WATER DEPTH
∿ FREQUENCY
δ = H/λ = fH/C1

FIG. 12. Water-wave dispersion observed on Bikini records from shots in lagoon area of type "A." Good agreement is obtained between actual dispersion and that predicted by theory.

explain the anomalously high group velocities by a lateral change in elasticity, the dispersion data give us a means of estimating the depth at which the discontinuity exists. The Airy waves, which are long enough to penetrate to about 300 feet, give velocity-period relations that fit the simple liquid bottom theory for a velocity of 6,250 feet/second everywhere in the lagoon. This is very close to the velocity indicated for this depth by the refraction data.

We thus infer from the dispersion data that there is a lateral change at least 80 feet deep in the character of the bottom sediments which follows the edge of the deep basin within the lagoon but that this change is no longer observed at a

FIG. 11. Bikini record traces showing Airy waves. First two traces show high-frequency dispersion also.

depth of 300 feet. If this inference is correct it would appear that there has been some relatively recent discontinuity in the sedimentary process by which the atoll has formed. It is possible that it is associated with the lowering of sea level which, according to Daly (1915), accompanied the Pleistocene glaciation.

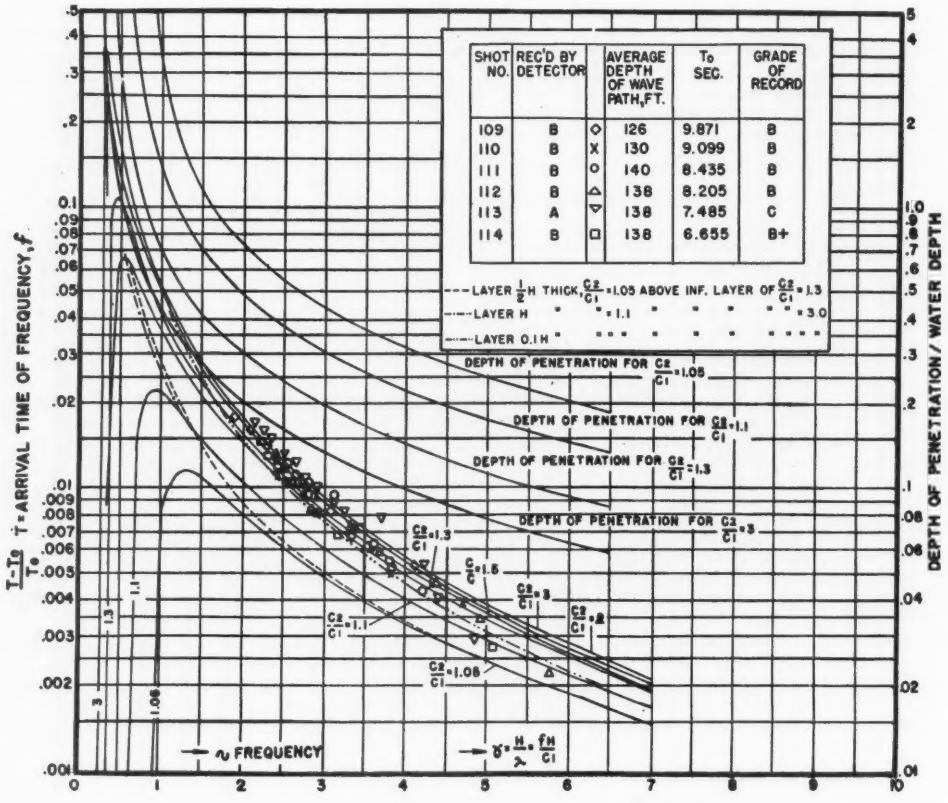
SHOT NO. | REC'D BY DETECTOR | AVERAGE DEPTH OF WAVE PATH, FT. | To SEC. | GRADE OF RECORD
109 | B | 126 | 9.871 | B
110 | B | 130 | 9.099 | B
111 | B | 140 | 8.435 | B
112 | B | 138 | 8.205 | B
113 | A | 138 | 7.485 | C
114 | B | 138 | 6.655 | B+
LAYER 1/2 H THICK, C2/C1 = 1.05 ABOVE INF. LAYER OF C2/C1 = 1.3
LAYER H " " = 1.1 " " " " = 3.0
LAYER 0.1 H " " " " " " " "
DEPTH OF PENETRATION FOR C2/C1 = 1.05
DEPTH OF PENETRATION FOR C2/C1 = 1.1
DEPTH OF PENETRATION FOR C2/C1 = 1.3
DEPTH OF PENETRATION FOR C2/C1 = 3
C2/C1 = 1.3
C2/C1 = 1.5
C2/C1 = 3
C2/C1 = 2
C2/C1 = 1.1
C2/C1 = 1.05
~ FREQUENCY
H/λ = H · f/C1
(T-To)/To · T = ARRIVAL TIME OF FREQUENCY, f
DEPTH OF PENETRATION / WATER DEPTH

FIG. 13. Water-wave dispersion observed on Bikini records from shots in lagoon area of type "B.' Deviation between theoretical and observed dispersion is within limits of experimental error.

DISPERSION IN "GROUND ROLL"

Well developed dispersion has been observed in Rayleigh waves generated by a shot-hole explosion and recorded by a Magnolia experimental seismic crew with an instrumental system passing frequencies as low as 5 cps. Vertical detectors were spaced every 50 feet for about 3,000 feet. The Rayleigh waves, identified by three-component instruments, showed an increasing number of cycles and covered an increasing time on the record as the distance from the source increased. This in itself would indicate that these waves are propagated dispersively. Figure 15 is a close-up of a single record showing Rayleigh waves. This exhibits a distinct decrease of period with time, just as did the Rayleigh waves

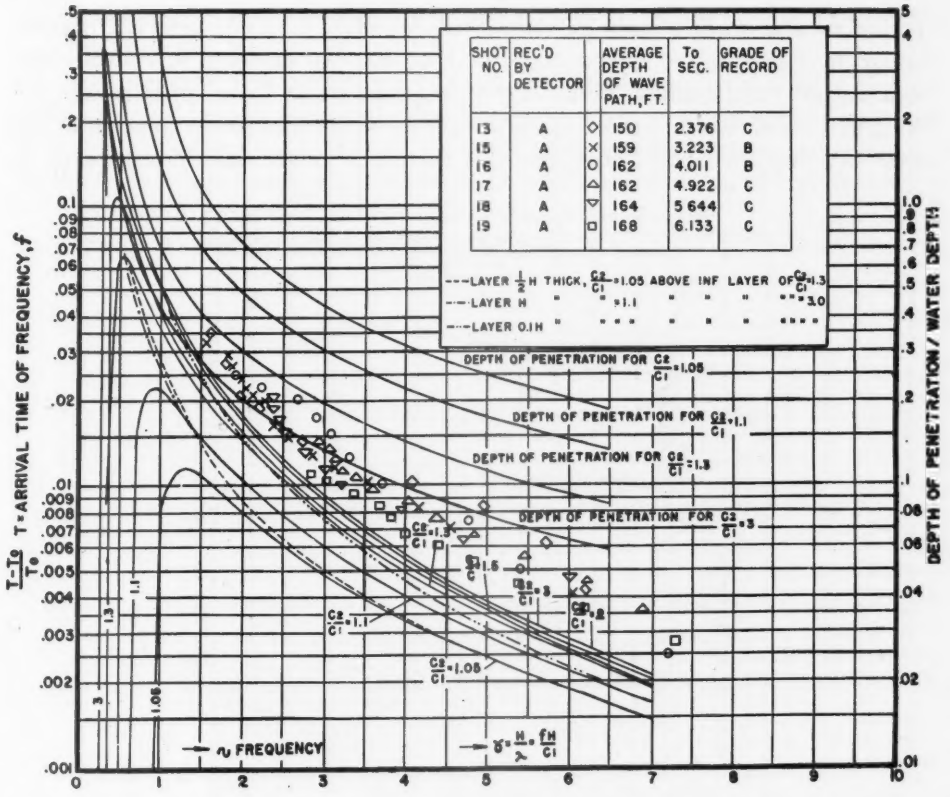
SHOT NO. | REC'D BY DETECTOR | AVERAGE DEPTH OF WAVE PATH, FT. | To SEC. | GRADE OF RECORD
13 A 150 2.376 C
15 A 159 3.223 B
16 A 162 4.011 B
17 A 162 4.922 C
18 A 164 5.644 C
19 A 168 6.133 C
---LAYER ½H THICK, C2/C1=1.05 ABOVE INF LAYER OF C2/C1=1.3
---LAYER H " " =1.1 " " " " =3.0
---LAYER 0.1H " " " " " " " "
DEPTH OF PENETRATION FOR C2/C1=1.05
DEPTH OF PENETRATION FOR C2/C1=1.1
DEPTH OF PENETRATION FOR C2/C1=1.3
DEPTH OF PENETRATION FOR C2/C1=3
T-To/To T=ARRIVAL TIME OF FREQUENCY, f
DEPTH OF PENETRATION / WATER DEPTH
FREQUENCY
γ=H/λ=fH/C1

FIG. 14. Water-wave dispersion observed on Bikini records from shots in lagoon area of type "C." Definite disagreement is obtained betweeen theory and observation.

from an earthquake shown in Figure 5. Figure 16 shows a group velocity versus period plot for this profile. The distance range covered is 750 to 3,200 feet. One sees that shot detector distance has little effect on dispersion characteristics. Figure 17 is a plot of the dispersion observed along a different profile in a region

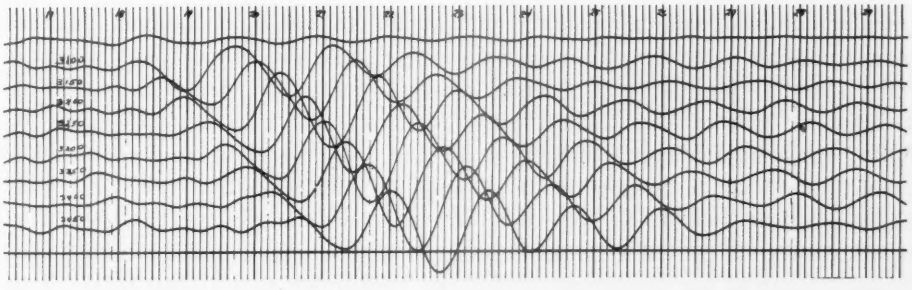

FIG. 15. Rayleigh waves recorded at 50 foot intervals from 5 lb. charge 25 feet deep in area with clay surface layer about 20 feet thick.

of similar near-surface geology. Both profiles give a group velocity pattern similar, over the limited spectrum covered, to that for Rayleigh waves obtained from distant earthquakes. This suggests that a surface layer, presumably the weathered zone, modifies the Rayleigh wave from the shot hole explosion in the same way that the earth's crust modifies the much longer earthquake waves. A

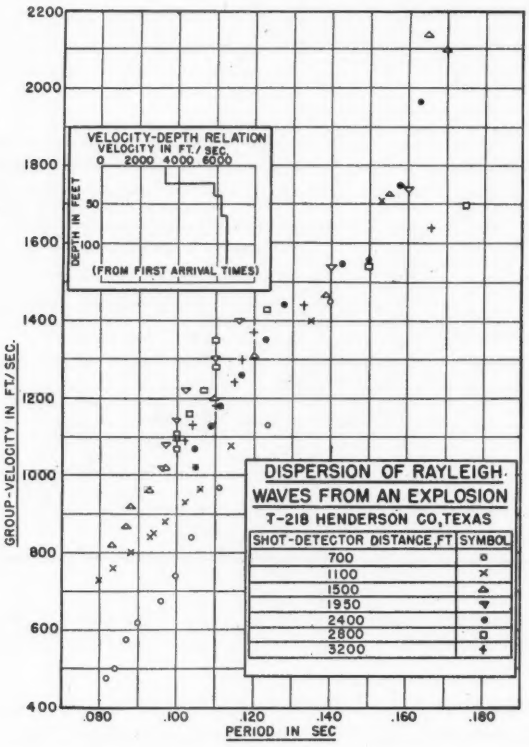

FIG. 16. Group velocity vs. period relations for Rayleigh waves in area in which record shown by Figure 15 was shot.

transformation of the abscissas from periods to wavelength/layer thickness makes possible more direct comparison with theory and shows that the ground roll dispersion data agree in order of magnitude with the theoretical curves developed by Sezawa and Jeffreys for solid layers and with those of Press and Ewing for a liquid layer overlying a solid. A more detailed comparison shows certain quantitative disagreements between the two types of curve. This would be expected because of the fact that the respective theories assume the surface layer to be a solid with a Poisson's ratio of 0.25 or else a liquid with no shear rigidity, whereas the highly unconsolidated weathered layer almost certainly departs from both simplifying assumptions. Actually, our knowledge of the mechanical properties of unconsolidated materials is sparse and it is possible that

dispersion data of this sort might give us some new and much needed information on this subject.

In prospecting one is particularly interested in progressive frequency changes which bring Rayleigh waves into the frequency range at which reflections occur. It is quite possible that in certain areas the thickness and elastic characteristics of the surface layer are such that Rayleigh waves could be quite troublesome in

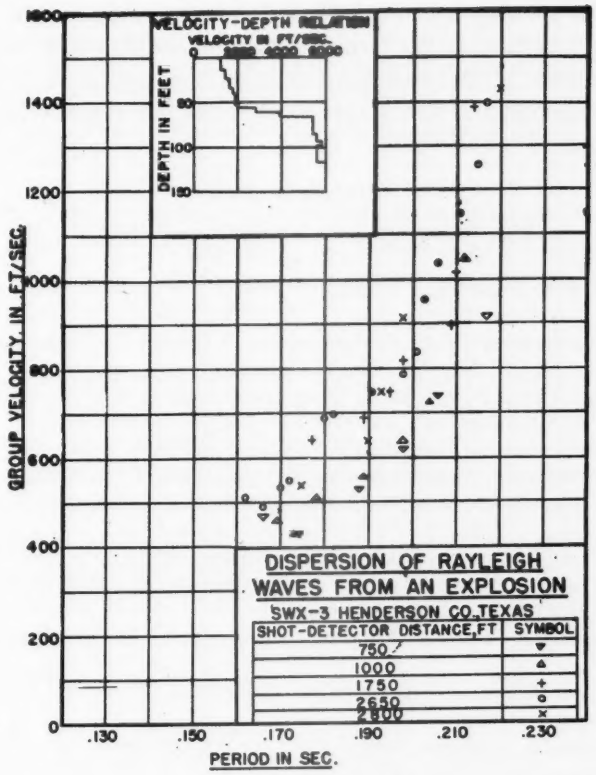

FIG. 17. Group velocity vs. period relations for Rayleigh waves in an area where surface layer thickness is greater than in that represented in Figure 16.

this respect. Further study would be needed to establish the conditions, if any, under which this might occur. Investigation along these lines is leading to a more satisfactory concept of how surface waves originate and how they might be eliminated by proper shooting procedures.

Neither the dispersion data from Bikini nor that from the ground roll observations by Magnolia have given us the textbook kind of agreement with theory, for in both cases the actual conditions were more complicated than those assumed in the theoretical treatment. In each example, however, comparison of observed dispersion with theory gave useful information. A further development of the

theory to include new and more complex cases as well as a wider use of existing theory should lead to additional applications. In any case, it is hoped that surface waves can be made a useful by-product rather than a waste product of seismic exploration.

ACKNOWLEDGMENT

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BIBLIOGRAPHY

Bullen, K. E. "On Rayleigh Waves Across the Pacific Ocean," *Mon. Not. Roy. Astr. Soc. Geoph. Suppl.*, 4 (1939) 579–582.

Daly, R. A. "The Glacial Control Theory of Coral Reefs," *Am. Acad. Arts Sci. Proc.*, 51 (1915) 155–251.

Dobrin, M. B. "Submarine Geology of Bikini Lagoon as Indicated by Dispersion of Water-Borne Explosion Waves," *Bull. Geol. Soc. Am.*, 61 (1950) 1091–1118.

———, B. Perkins, Jr., and B. L. Snavely, "Subsurface Constitution of Bikini Atoll as Determined by a Seismic Refraction Survey," *Bull. Geol. Soc. Am.*, 60 (1949) 807–828.

Gutenberg, B. "Dispersion und Extinktion von Seismischen Oberflachenwellen und der Aufbau der Obersten Erdschichten," *Physik Zeitschrift*, 25 (1924) 377–381.

Jeffreys, Harold. "The Surface Waves of Earthquakes," *Mon. Not. Roy. Astr. Soc. Geoph. Suppl.*, 3 (1935) 253–261.

Love, A. E. H. "Some Problems in Geodynamics," Cambridge University Press (1911) pp. 160–165.

Pekeris, C. L., "Theory of Propagation of Explosive Sound in Shallow Water," *Propagation of Sound in the Ocean, Geol. Soc. Am. Memoir 27* (1948).

Press, F. and M. Ewing. "Low Speed Layer in Water-Covered Areas," *Geophysics*, XIII (1948a) 404–420.

———. "A Theory of Microseisms with Geological Applications," *Trans. Am. Geophys. U.*, 29 (1948b) 163–174.

———. "Propagation of Explosive Sound in a Liquid Layer Overlying a Semi-Infinite Elastic Solid," *Geophysics*, XV (1950) 426–446.

Rayleigh, Lord, "On Waves Propagated Along the Plane Surface of an Elastic Solid," *Proc. London Math. Soc.*, 17 (1885) 4–11.

Sezawa, K., "Dispersion of Elastic Waves Propagated on the Surface of Stratified Bodies and on Curved Surfaces," *Bull. Earthquake Res. Inst., Tokyo*, 1 (1929) 1–18.

———. "Rayleigh and Love Waves Transmitted Through the Pacific Ocean and the Continents," *Bull. Earth. Res. Inst., Tokyo*, 13 (1935) 245–249.

Stoneley, R. "The Continental Layers of Europe," *Bull. Seis. Soc. Am.*, 38 (1948) 263–274. References are given here to Stoneley's earlier contributions to the subject.

Wilson, J. T., and O. Baykal. "Crustal Structure of the North Atlantic Basin as Determined from Rayleigh Wave Dispersion," *Bull. Seis. Soc. Am.*, 38 (1948) 44.

———. "Increase in Period of Earthquake Surface Waves with Distance Traveled," *Bull. Seis. Soc. Am.*, 38 (1948) 91.

Worzel, J. L., and M. Ewing. "Explosion Sounds in Shallow Water," in *Propagation of Sound in the Ocean, Geol. Soc. Am. Memoir 27* (1948).

SEISMIC REFRACTION WITH VARIABLE VELOCITY*

JEAN M. GOGUEL†

ABSTRACT

The results of an investigation of methods of interpreting and calculating the propagation of seismic waves with variable velocity in contrast to an assumed constant velocity is presented. One of the major purposes of this study is to establish a calculation method for use in seismic refraction work that can be applied to existing types of alluvia and similar geologic formations. In addition to presenting the necessary tables and graphs used for such computations, two examples from actual field experience are presented.

At the present time, seismic refraction finds its main application in exploration of shallow structures, particularly in civil engineering. The upper part of geological formations encountered in seismic prospecting is generally made up of alluvia and other soft grounds, where the velocity is not constant and increases with depth. The classical method consists in dividing these formations into a conventional series of layers of constant velocity. The thickness of two or three layers have to be estimated and the fact that they are purely fictitious is frequently overlooked in the interpretation. This paper is concerned with the study of propagation of seismic waves with variable velocity for the purpose of establishing a method of calculation that could be applied to such alluvia.

Only longitudinal waves, the fastest ones, will be considered. Their velocity $V=f(y)$ is assumed to depend solely upon the depth y. A seismic ray subtends the angle i with the vertical (Figure 1). It is well known that $V/\sin i=M$, where M is a constant. Also $ds^2=dx^2+dy^2$, $ds/dt=V=f(y)$, $dx/ds=\sin i=F(y)/M$. Hence

$$x=\int_0 \frac{f(y)dy}{\sqrt{M^2-f(y)^2}}, \tag{1}$$

$$t=\int_0 \frac{Mdy}{f(y)\sqrt{M^2-f(y)^2}}. \tag{2}$$

For a given seismic ray, apparent path x and travel time t, back to surface are given by:

$$x=2\int_0^{y_m} \frac{f(y)dy}{\sqrt{M^2-f(y)^2}}, \tag{1a}$$

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† Paris, France.

$$t = 2\int_0^{y_m} \frac{M\,dy}{f(y)\sqrt{M^2 - f(y)^2}}, \tag{2a}$$

assuming $f(y_m) = M$.

The dromochrone (time-distance curve) will be obtained by plotting points corresponding to different values of M. Its slope corresponds to the maximum velocity M, which is reached by the seismic ray at its lowest point where sin 90° equals *one*. Consider two rays very close from one another. The travel time to any

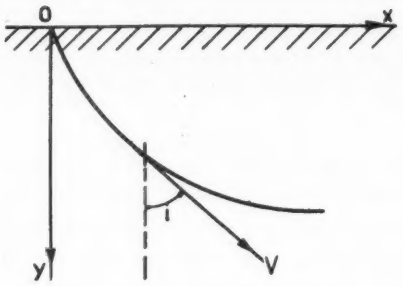

FIG. 1. Ray path for linear increase of velocity with depth.

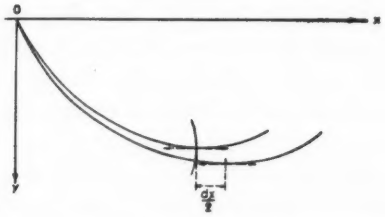

FIG. 2. Path differences for close key paths.

wave front normal to the two rays is the same, and the differences in apparent path and total travel time correspond to an arc on the lowest part of the trajectory shown in Figure 2.

Usually, actual dromochrones plotted from recorded data are not accurate enough to give a relationship between velocity and depth (Ewing and Leet, 1932). A general formula must be assumed *a priori*, several instances will be given later on, and the parameters are determined from the experimental data. When the relationship depends upon two parameters only, a bi-logarithmic diagram can be used. A mere translation will bring the experimental points on the theoretical curve which is plotted only once. The values of the parameter will be deduced from the position of the axes as shown in Figure 21.

More generally, this method permits a choice among different forms of relationships. In a given survey, a single general formula shall generally be used for the interpretation of all the data, whether or not constant values are assigned to the parameters. For the purpose of choosing this formula, experimental points

must be checked against various theoretical curves. At the same time it is possible to limit the range outside whose points pertain to other branches of the dromochrone.

Once the parameters have been thus determined, the thickness of the variable velocity medium is computed, and also the thickness of the underlying layers, each being assumed to have a constant velocity V_2, V_3, etc. shown as in Figure 3.

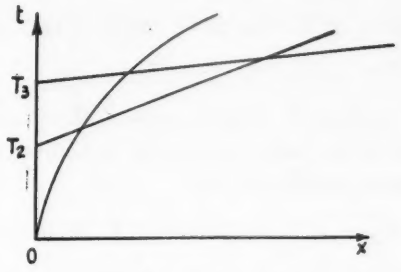

FIG. 3

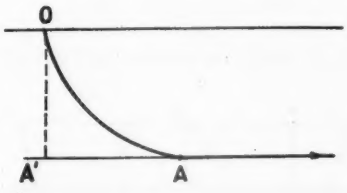

FIG. 4

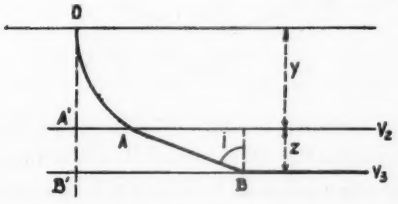

FIG. 5

In Figure 4, consider a seismic wave refracted in the second layer where $M = V/\sin i = V_2$. Since the shot point and the emerging point are symmetrical, the intercept T_2 is twice the difference between the travel time t along the path OA and the time x/V_2 which would have been required to travel along the horizontal projection $A'A$ at the velocity V_2. Knowing the value of the constant $M = V_2$, it will be possible to obtain the thickness y of the first layer from the intercept $T_2 = 2(t - x/V_2$ through the use of tables given in the Appendix.

If several constant speed layers can be considered, the same tables will enable a quick computation of their thicknesses. For example, consider the seismic ray

horizontally refracted in the third layer as shown in Figure 5 where $M = V/\sin i = V_2/\sin i_2 = V_3$.

The travel time from O to B is made up of the travel time t from O to A and the time $z/(V_2 \cos i_2)$ required to travel along AB, at the velocity V_2. The horizontal projection is the sum of $A'A = x$ and the horizontal projection of $AB = z \tan i_2$. At the velocity V_3, the corresponding travel time is $x/V_3 + z \tan i_2/V_3$. The intercept T_3 is therefore:

$$\begin{aligned} T_3 &= 2[t - x/V_3 + z(1/V_2 \cos i_2 - \tan i_2/V_3)] \\ &= 2[t - x/V_3 + z \cos i_2/V_2]. \end{aligned} \tag{3}$$

The table gives the values of $t - x/V_3$ versus $M = V_3$ and y, thickness of the first layer. Therefore, z is the only unknown. A similar computation for a ray refracted in a fourth layer would lead to:

$$T_4 = 2[t - x/V_4 + (z \cos i_2)/V_2 + (s \cos i_3)/V_3] \tag{4}$$

As a first approximation, it may be assumed that velocity is proportional to depth:

$$V = V_0(1 + y/h). \tag{5}$$

Using general equations, it could be shown that seismic rays are circles centered

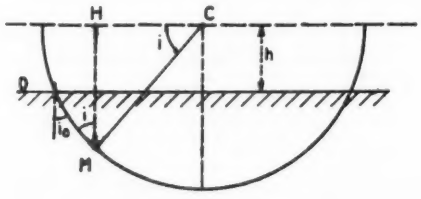

FIG. 6

on the line $y = -h$, but it is easier to show it directly in Figure 6. The velocity is, by hypothesis, proportional to the distance MH to the horizontal passing through the center and therefore the radius $R = MH/\sin i$ is a constant.

The length of the apparent path is $x = 2\ h \cot i_0$, and the corresponding travel time is

$$t = (2h/V_0) \log \cot (i_0/2). \tag{6}$$

The travel time between two points corresponding to angles i_0 and i_1 is:

$$t = (h/V_0)[\log \tan (i_1/2) - \log \tan (i_0/2)] \tag{7}$$

The equation of the dromochrone can be obtained by eliminating i_0 between x and t. For this purpose, it is convenient to introduce reduced coordinates such that $\xi = x/2h$ and $\tau = V_0 t/2h$. Thus

$$\xi = \sinh \tau \qquad \text{or} \qquad x = 2h \sinh (V_0 t/2h). \tag{8}$$

It is now obvious that the slope of the dromochrone, $dx/dt = V_0 \cosh (V_0 t/2h)$ corresponds to the maximum speed reached at the lowest point of the seismic ray, since the radius of the circle is

$$R = \sqrt{h^2 + (x/2)^2} = h \cosh (V_0 t/2h) \tag{9}$$

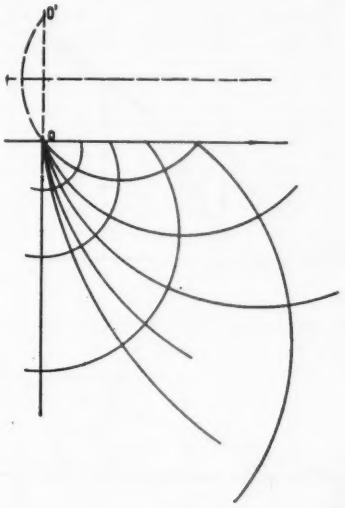

FIG. 7. Section of waves-surfaces, for linear variation of velocity.

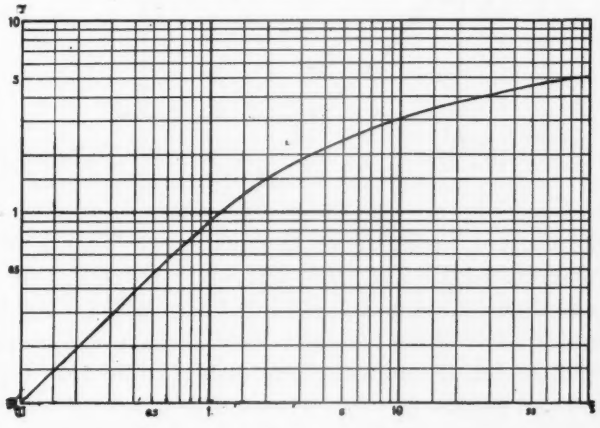

FIG. 8

Wave fronts, or the loci of points reached at the same time by a given wave, must be orthogonal to the seismic ray and, therefore, they are conjugate spheres of the circles of the series defined by the origin and the symmetrical point with respect to the plane $-h$ shown in Figure 7. Figure 8 shows a plot of the dromochrone on bi-logarithmic graph paper. A check against experimental points will

show if the assumed relationship agrees well and how closely it fits. The value of the parameters h and h/V_0 will be determined at the same time.

These parameters also can be obtained without recourse to logarithmic plotting. Referring to Figure 9, a dromochrone is traced through the experimental

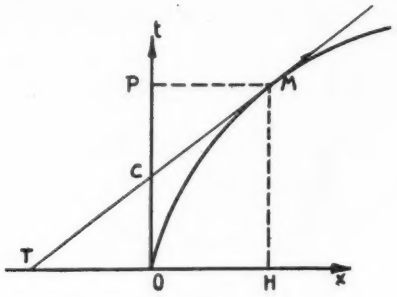

FIG. 9

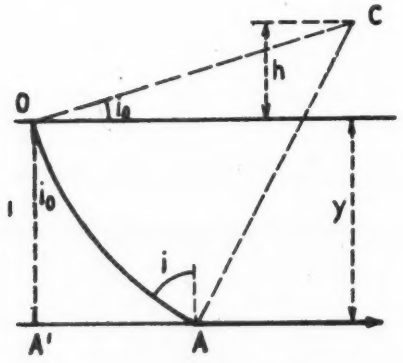

FIG. 10

points, with the tangent to the curve at a point x, t. Then $\lambda=(dx/dt)/(x/t)$ is given on the diagram by $\lambda=TH/OH=TM/CM=OP/CP$, and depends solely upon reduced coordinates: $\lambda=\tau/\tanh\tau$. Table I correlates ξ, τ and λ, and therefore enables the computation of $h=x/2\xi$ and $V_0=2h\tau/t$. It will be possible then to complete the plot of the theoretical curve, using Table I, in order to check it against experimental points.

In order to compute the thickness y of the variable speed layer above a constant speed layer (Figure 10), it will be noted that the horizontally refracted seismic ray in the latter layer subtends angles with the vertical, i_0 at the surface, where $\sin i_0=V_0/V_2$ and i_1 at the bottom of the first layer, $\sin i_1=V_1/V_2=(V_0/V_2)(1+y/h)$, and $A'A=h(\cos i_0-\cos i_1)/\sin i_0$

The travel time from O to A is

$$t=(h/V_0)[\log\cot(i_0/2)-\log\cot(i_1/2)]. \qquad (10)$$

TABLE I

REDUCED COORDINATES FOR A LINEAR VARIATION OF VELOCITY
$\xi = \sinh \tau \; \lambda = (d\xi/d\tau)/(\xi/\tau) = \tau \tanh \tau$

τ	ξ	λ	τ	ξ	λ	τ	ξ	λ
0.1	0.1000	1.005	1.1	1.3356	1.370	2.1	4.0219	2.165
0.2	0.2015	1.011	1.2	1.5094	1.441	2.2	4.4570	2.250
0.3	0.3049	1.027	1.3	1.6980	1.510	2.3	4.9368	2.340
0.4	0.4108	1.052	1.4	1.9045	1.581	2.4	5.4670	2.440
0.5	0.5210	1.080	1.5	2.1291	1.657	2.5	6.0500	2.535
0.6	0.6360	1.118	1.6	2.3756	1.736	2.6	6.6950	2.630
0.7	0.7580	1.160	1.7	2.6456	1.820	2.8	8.1920	2.822
0.8	0.8880	1.205	1.8	2.9422	1.903	3.0	10.0170	3.015
0.9	1.0267	1.257	1.9	3.2681	1.987	3.2	12.2460	3.210
1.0	1.1751	1.313	2.0	3.6268	2.075	3.4	16.5420	3.505

TABLE II

LINEAR VARIATION OF VELOCITY WITH DEPTH. COMPUTATION OF THICKNESS OF LAYERS
$\psi(\sin i) = \log \cot (i/2) - \cos i$

$\sin i$	ψ	$\sin i$	ψ	$\sin i$	ψ	$\sin i$	ψ
0.00	∞	0.25	1.097	0.50	0.450	0.75	0.136
		0.26	1.060	0.51	0.435	0.76	0.125
		0.27	1.020	0.52	0.420	0.77	0.119
		0.28	0.990	0.53	0.400	0.78	0.110
		0.29	0.960	0.54	0.385	0.79	0.100
0.05	2.821	0.30	0.920	0.55	0.370	0.80	0.093
0.06	2.504	0.31	0.890	0.56	0.355	0.81	0.085
0.07	2.352	0.32	0.860	0.57	0.340	0.82	0.079
0.08	2.217	0.33	0.830	0.58	0.330	0.83	0.071
0.09	2.102	0.34	0.800	0.59	0.315	0.84	0.064
0.10	2.005	0.35	0.770	0.60	0.300	0.85	0.058
0.11	1.970	0.36	0.750	0.61	0.285	0.86	0.052
0.12	1.830	0.37	0.725	0.62	0.272	0.87	0.046
0.13	1.740	0.38	0.695	0.63	0.260	0.88	0.041
0.14	1.670	0.39	0.672	0.64	0.250	0.89	0.037
0.15	1.600	0.40	0.650	0.65	0.238	0.90	0.032
0.16	1.540	0.41	0.630	0.66	0.225	0.91	0.027
0.17	1.480	0.42	0.610	0.67	0.212	0.92	0.022
0.18	1.420	0.43	0.585	0.68	0.200	0.93	0.017
0.19	1.370	0.44	0.565	0.69	0.190	0.94	0.013
0.20	1.330	0.45	0.540	0.70	0.180	0.95	0.010
0.21	1.270	0.46	0.520	0.71	0.170	0.96	0.007
0.22	1.220	0.47	0.505	0.72	0.160	0.97	0.005
0.23	1.170	0.48	0.490	0.73	0.152	0.98	0.003
0.24	1.130	0.49	0.470	0.74	0.143	0.99	0.001

The intercept T_2 is twice the difference between t and the travel time from A' to A at the velocity V_2 which is $(\cos i_0 - \cos i_1)h/V_0$. Hence

$$T_2 = (2h/V_0)[(\log \cot (i_0/2) - \cos i_0) - (\log \cot (i_1/2) - \cos i_1)]. \quad (11)$$

Let $\psi(\sin i) = \log \cot (i/2) - \cos i$. Values of this function are given in Table II.

Thus

$$T_2 = (2h/V_0)[\psi(V_0/V_2) - \psi(V_1/V_2)] \tag{12}$$

which gives $\psi(V_1/V_2)$; V_1/V_2 is obtained from Table II and finally y is computed using the equation $1+y/h=(V_1/V_2)/(V_0/V_2)$.

A similar procedure will be followed if, below the variable velocity alluvia,

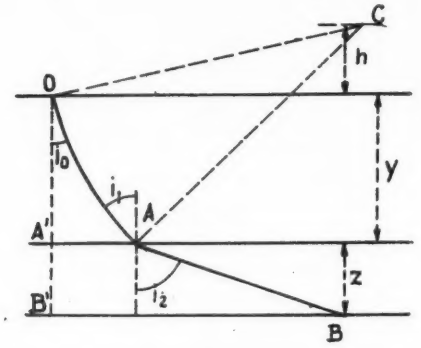

FIG. 11

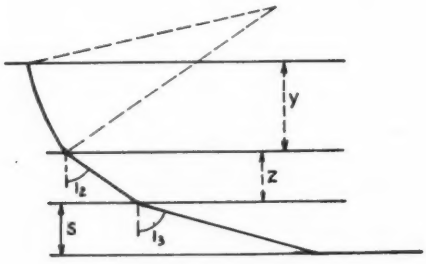

FIG. 12

there are two or several layers characterized by different velocities as shown in Figure 11 where:

$$\sin i_0 = V_0/V_3, \quad \sin i_1 = V_1/V_3, \quad \sin i_2 = V_2/V_3;$$

$A'A = h\ (\cos i_0 - \cos i_1)/\sin i_0$; $B'B - A'A = z \tan i_2$; and the travel time in the first layer is $(h/V_0)[\log \cot(i_0/2) - \log \cot(i_1/2)]$, and in the second layer it is $z/V_2 \cos i_2$. The time intercept is

$$T_3 = (2h/V_0)[\psi(V_0/V_3) - \psi(V_1/V_3) + z \cos i_2/V_2] \tag{13}$$

from which the thickness z is obtained.

If four layers are present, as shown in Figure 12,

$$T_4 = (2h/V_0)[\psi(V_0/V_4) - \psi(V_1/V_4) + z \cos i_2/V_2 + s \cos i_3/V_3]. \tag{14}$$

Because it is very easy to construct seismic rays geometrically it is possible to begin the study of propagation in a series of layers where the velocity is a linear function of depth. Actually, characteristics of such layers cannot be obtained from experimental dromochrones. The reverse operation will be considered here, and seismic rays will be constructed and travel times will be computed for a set of given layers.

A layer limited by the ordinates y_{n-1} and y_n is characterized by a velocity-depth relationship such as $V=V_n(1+y/h_n)$. In this layer, the seismic rays are circles centered in the plane $y=h_n$.

If the velocities vary continuously from one layer to the next one, the corresponding circles are tangent and their construction is obvious. If the velocity is

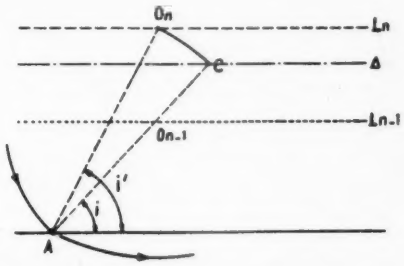

FIG. 13. Construction of seismic rays, for several layers with linear velocity-depth relationship.

discontinuous, the ray is refracted according to the relation $V/\sin i=$ constant, then $\sin i_n/\sin i_n'=N_n$ a constant. The construction may be performed as shown in Figure 13. $O_{n-1}A$ cuts a fixed straight line Δ at C. With a as center and AC as a radius, describe a circle which cuts at O_n the straight line, locus of the centers in the second medium. O_n is the center of the circle, path of the seismic ray, in the layer n, if the straight line Δ is such that N_n is the ratio of its distance to the layer interface to its distance to the straight line, locus of O_n.

Let i_0 be the angle of incidence at the surface, then

$$R_1 = h_1/\sin i_0, \quad \sin i_1 = \frac{h_1 + y_1}{h_1} \sin i_0, \quad \text{and} \quad \sin i_1' = \frac{h_1 + y_1}{N_1 h_1} \sin i_0,$$

$$R_2 = \frac{h_2 + y_1}{\sin i_1'} = \frac{N_1(h_2 + y_1)}{h_1 + y_1}, \quad R_1 = \frac{N_1 h_1(h_2 + y_1)}{(h_1 + y_1)\sin i_0}, \tag{15}$$

$$\sin i_2 = \frac{(h_2 + y_2)(h_1 + y_1)\sin i_0}{N_1(h_2 + y_1)h_1} \quad \text{and} \quad \sin i_2' = \frac{(h_2 + y_2)(h_1 + y_1)\sin i_0}{N_1 N_2(h_2 + y_1)h_1}.$$

$$R_3 = \frac{N_1 N_2 h_1(h_2 + y_1)(h_3 + y_2)}{(h_1 + y_1)(h_2 + y_2)\sin i_0} \text{ etc.}$$

The length of the apparent path, x, is given by:

$$x/2 = R_1(\cos i_0 - \cos i_1) + R_2(\cos i_1' - \cos i_2) + R_3(\cos i_2' - \cos i_3) + \qquad (16)$$

where R_n are products of constants by $1/\sin i_0$.

The travel time is given by:

$$\begin{aligned} t/2 = {} & (h_1/V_1)(\log \tan (i_1/2) - \log \tan (i_0/2)) \\ & + (h_2/V_2)\left[(\log \tan (i_2/2) - \log \tan (i_1'/2)\right] \cdot \end{aligned} \qquad (17)$$

The construction of a series of seismic rays allows an analysis of certain pe-

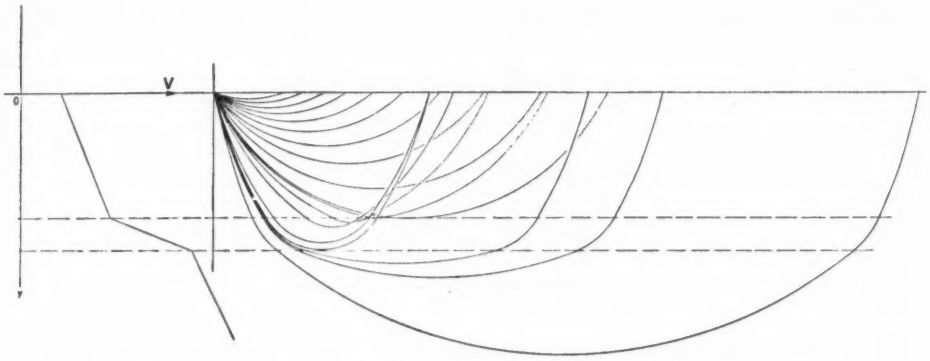

FIG. 14. Several seismic rays, for velocities indicated by left hand diagram.

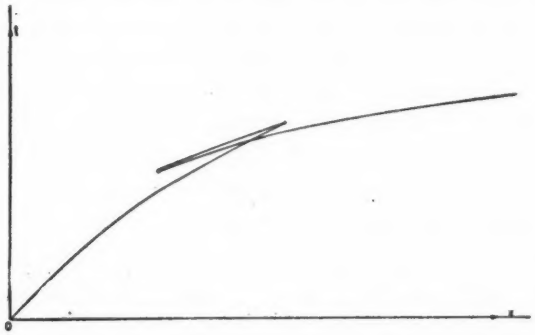

FIG. 15. Complete dromochrone, for the seismic rays shown on figure 14.

culiarities of propagation. For instance, consider a layer of alluvia where the velocity increases steadily, followed by a transition layer where the variation of velocity is very rapid, and finally a layer where the variation is slow, such as bed rock. The dromochrone shown in Figure 15 is obtained from the construction of a series of seismic rays, for which travel times have been computed from Figure 14. The cusps in the dromochrone indicate some sort of focalization of the seismic rays, which results in an accumulation of energy after the first impulse.

Seismic rays cannot be considered as materializing propagation of energy, as is the case in optics, because of the occurrence of two types of waves, longitudinal and transverse, progressing at different velocities. In reflections and refractions, part of the energy may be transferred from the longitudinal to the transverse type and conversely, and this probably holds true in this continuous refraction constituted by propagation at variable velocity. Nevertheless, the construction of seismic rays yields a first approximation of the distribution of energy, which could not have been obtained with the common assumption of constant speed layers.

A second example of the usefulness of this method can be given. Assume that

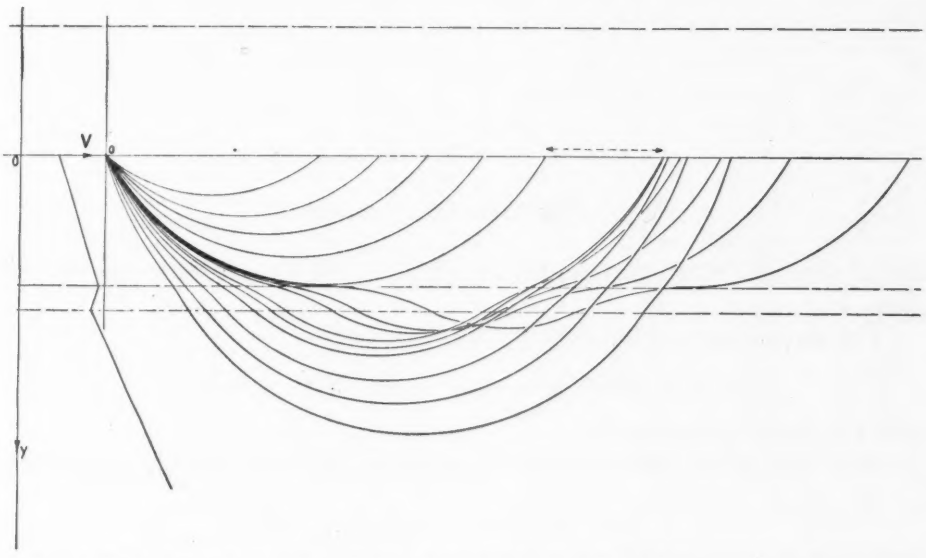

FIG. 16. Path of seismic rays, for velocities indicated by the left hand diagram; note the zone of silence that is not reached by any seismic rays.

the velocity starts decreasing at a certain depth as shown in Figure 16. By considering seismic rays, it can be shown that a zone of silence will result, and its extent can be forecast. However, in order to obtain accurate results, a second derivative of velocity versus depth should be taken into account, at least near the maxima and minima. Because of such considerations, it has been possible to forecast the amazing range of sound in sea at the level of a velocity minimum.

Consider now a velocity of propagation proportional to the square root of the depth, $V=k\sqrt{y}$. The seismic rays are cycloids, since for this curve $\sin i = \sqrt{y}/a$. and $V/\sin i = k\sqrt{a} = M$. The law of propagation is the same as the law for the generation of the cycloid by the uniform rolling of its basis circle. From Figure 17

$$x = (a/2)(\omega - \sin \omega), \tag{18}$$

$$y = (a/2)(1 - \cos \omega), \tag{19}$$

with $i = \omega/2$ and $t = \omega\sqrt{a}/k$

The length of the apparent path is $x = \pi a$, and the travel time is $t = 2\pi\sqrt{a}/k$

The equation of the dromochrone is

$$x = k^2t^2/4\pi \tag{20}$$

which represents a parabola. On bi-logarithmic graph paper, it will be a straight

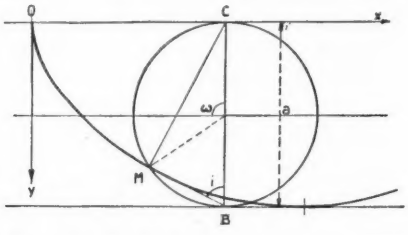

FIG. 17. Path of seismic ray along a cycloid.

line of slope $k/2$ which may readily be computed for a check with experimental data.

The wave fronts are homothetics of the curve

$$x = (1/\omega^2)(\omega - \sin \omega) \quad y = (1/\omega^2)(1 - \cos \omega),$$

which is shown in Figure 18.

If a layer at constant velocity V_2 underlies the layer which has just been

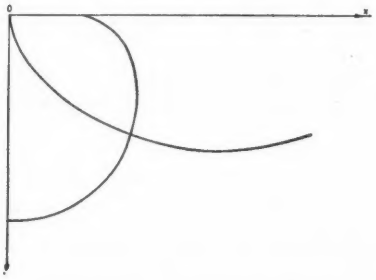

FIG. 18. Section of wave surface.

studied, the value V_2 will be read on the dromochrone which contains a segment of straight line. From this the parameter a_2 of the cycloid corresponding to the ray which returns to the surface through the second medium is $a_2 = (V_2/k)^2$. The point of incidence A on the interface corresponds to a value of ω such that $y = (a_2/2)(1 - \cos \omega)$. The travel time is $t = \omega\sqrt{a_2}/k$, and the abscissa

$x=(a_2/2)(\omega-\sin\omega)$. The intercept of the straight line segment of the dromochrone on the time axis is therefore:

$$T_2 = (V_2/k^2)(\omega + \sin\omega)\,. \tag{21}$$

Table III gives the relationship of $(1-\cos\omega)$ against $(\omega+\sin\omega)$ and thus the thickness y of the first layer is obtained readily for the intercept time T_2. Similarly, if the dromochrone contains several segments of straight lines, aside from

TABLE III

COMPUTATION OF CYCLOIDAL SEISMIC RAYS HAVING THE VELOCITY-DEPTH RELATIONSHIP
$V=k\sqrt{y}$ $x=a/2(\omega-\sin\omega)$ $y=a/2(1-\cos\omega)$ $t=2\pi\sqrt{a}/k$
COMPUTATION OF THICKNESS OF LAYER: $T_2=(V_2/k^2)(\omega+\sin\omega)$

ω	$\omega-\sin\omega$	$1-\cos\omega$	$\omega+\sin\omega$	ω	$\omega-\sin\omega$	$1-\cos\omega$	$\omega+\sin\omega$
0	0	0	0	1.6581	0.6620	1.0871	2.6542
0.0873	0.0001	0.0038	0.1744	1.7453	0.7605	1.1736	2.7301
0.1745	0.0009	0.0152	0.3482	1.8325	0.8665	1.2588	2.7980
0.2618	0.0030	0.0341	0.5206	1.9200	0.9803	1.3420	2.8597
0.3490	0.0070	0.0603	0.6910	2.0072	1.1010	1.4226	2.9135
0.4363	0.0137	0.0937	0.8589	2.0944	1.2284	1.5000	2.9607
0.5236	0.0236	0.1340	1.0236	2.1817	1.3213	1.5736	3.0008
0.6108	0.0372	0.1808	1.1844	2.2690	1.5030	1.6428	3.0350
0.6981	0.0553	0.2340	1.3309	2.3563	1.6492	1.7071	3.0634
0.7854	0.0783	0.2929	1.4925	2.4434	1.8006	1.7660	3.0862
0.8727	0.1067	0.3572	1.6387	2.5307	1.9571	1.8191	3.1043
0.9600	0.1409	0.4264	1.7791	2.6180	2.1180	1.8660	3.1180
1.0472	0.1812	0.5000	1.9132	2.7053	2.2827	1.9063	3.1279
1.1340	0.2280	0.5574	2.0400	2.7925	2.4505	1.9397	3.1345
1.2217	0.2820	0.6580	2.1614	2.8798	2.7210	1.9660	3.1387
1.3090	0.3430	0.7412	2.2750	2.9670	2.7940	1.9848	3.1400
1.3960	0.4110	0.8264	2.3810	3.0540	2.9670	1.9962	3.1411
1.4835	0.4874	0.9129	2.4796	3.1416	3.1416	2.0000	3.1416
1.5708	0.5708	1.0000	2.5708				

the initial parabola, it will be easy to compute the thickness of the following layers. The parameter of the cycloid corresponding to the ray which returns to the surface through the third layer is $a_3=(V_3/k)^2$ (ω_3), corresponding to the incident point, whose value is such that $y=(a_3/2)(1-\cos\omega_3)$ and the intercept is

$$T_3 = (V_3/k^2)(\omega_3 + \sin\omega_3) + 2z\cos i_2/V_2 \tag{22}$$

from which z can be found.

Similarly,

$$T_4 = (V_4/k^2)(\omega_4 + \sin\omega_4) + 2z\cos i_2'/V_2 + 2s\cos i_3/V_3 \tag{23}$$

where ω_4 is such that:

$$y = (1/2)(V_4/k)^2(1 - \cos\omega_4)\,. \tag{24}$$

The preceding assumption can be generalized. Consider a law $V=ky^n$, where $0<n<1$. Write $V/\sin i=M=ka^n$ The general equations are now:

$$x = k\int_0 \frac{y^n dy}{\sqrt{M^2 - ky^{2n}}}, \tag{25}$$

$$t = \int_0 \frac{M dy}{ky^n\sqrt{M^2 - k^2y^{2n}}}, \tag{26}$$

or, by writing $\xi = x/a$, $\eta = y/a$ and $\tau = tM/a = ka^{n-1}t$,

$$\xi = \int_0 \frac{\eta^n d\eta}{\sqrt{1 - \eta^{2n}}}, \tag{27}$$

$$t = \int_0 \frac{d\eta}{\eta^n\sqrt{1 - \eta^{2n}}}. \tag{28}$$

Let α and β be the values of these integrals taken between 0 and 1. The equation of the dromochrone is then $x = 2\alpha a$, $t = 2\beta a^{1-n}/k$ or, by eliminating a, $t = (2\beta/k)(x/2\alpha)^{1-n}$ which is a parabola of degree $1-n$ or $1/(1-n)$, which on plotting on bi-logarithmic graph paper is a straight line with a slope $1-n$.

The change of variable $\sin i = \eta^n$ would yield

$$\xi = (1/n)\int_0^i \sin^{1/n} i\, di \tag{29}$$

and

$$\tau = (1/n)\int_0^i \sin^{(1/n-2)} i\, di\,. \tag{30}$$

These integrals can be computed directly only if $1/n$ is an integer. If it is not, an approximate value would be obtained either by graphical integration or by numerical approximation.

From the experimental dromochrone one can find first, the value of n, and then, the value of k. If a constant velocity layer lies under the variable velocity layer, the corresponding value V_2 will be read directly on the straight line portion of the dromochrone. Then, for the seismic ray which travels through this medium and emerges, the value of parameter a is obviously $a = (V_2/k)^{1/n}$.

The intercept of the straight line portion is $T_2 = 2(t - x/V_2)$ where $x = a\xi(i)$ and $t = \tau(i)/ka^{n-1}$, with i function of y defined by $\sin i = (y/a)^n$.

Therefore

$$T_2 = 2V_2^{(1/n-1)}\, k^{1/n}\, (\tau(i) - \xi(i))\,. \tag{31}$$

Knowing ξ and τ with respect to i, it is possible to tabulate values of $\tau - \xi$ and $\eta = \sin^{1/n} i$, and since $y = (V_2/k)^{1/n}\eta)$, the thickness y of the layer can be computed from T_2. Similarly, when a third layer of velocity V_3 is present, $\sin i_3 = ky^n/V_3$, $\sin i' = V_2/V_3$ and

$$T_3 = 2V_3^{(1/n-1)}\, k^{-1/n}\, (\tau(i_3) - \xi(i_3)) + 2z\cos i'/V_2\,. \tag{32}$$

If, during a survey, it appears that dromochrones plotted on logarithmic coordinates start as straight lines with a slope $1-n$, it will be easy to compute the functions $\xi(i)$ and $\tau(i)$ corresponding to the velocity-depth relationships $V=ky^n$ and to tabulate values of $\tau-\xi$ and $\sin^{1/n} i$. With the aid of this table, the interpretation of dromochrones will become very rapid. In order to gain time, it might be advisable to establish before hand a set of such tables or curves for various values of n.

Example: Assume $n=1/3$ $V=k\sqrt[3]{y}$

$$\xi = 3\int_0^i \sin^3 i\,di = 2 - 3\cos i + \cos^3 i \qquad \tau = 3\int_0^i \sin i\,di = 3(1-\cos i)\,.$$

The limits of the integral being 0 and $\pi/2$, $\alpha=2$ and $\beta=3$. The equation of the dromochromic curve is $t=(2.37/k)x^{2/3}$. On logarithmic graph paper, the curve is a straight line with a slope $2/3$. Only one point of the dromochrone will be required in order to obtain k.

On a seismic ray where

$$x = a(2 - 3\cos i + \cos^3 i); \quad y = a\sin^3 i; \quad t = (3a^{2/3}/k)(1-\cos i).$$

If a second layer of uniform velocity V_2 occurs, the thickness y of the first layer is deduced from the intercept time, since

$$T_2 = (2V_2^2/k^3)(1-\cos^3 i) \quad \text{with} \quad y = (V_2/k)^3 \sin^3 i.$$

The first equation yields a value for i, that is used in the second one. The calculation is so rapid that it is not necessary to use special tables.

During shooting performed on the plateau of Mont Cenis (French Alps), the following data were observed

x	10	40	70	100	130	160	meters
t	0.026	0.069	0.097	0.112	0.126	0.141	seconds

The classical method would consist in dividing the dromochrone in three straight line portions corresponding to constant velocities 300, 700 and 2,060 m/sec. The intercepts would be, respectively 0.012 and 0.063 second. This would lead to a thickness of two meters for the first layer, which does not have any geological signification, and to a depth of 20.5 meters for the bed rock.

The logarithmic diagram shows that the three first points are on a straight line of slope $2/3$ (see Fig. 19). Therefore, the equations just established for $V=ky^{1/3}$ can be applied.

The value of k is obtained immediately by substituting the coordinates of one point (70 m. 0.097 sec):

$$k = (2.37)(70)^{2/3}/0.097 = 415$$

The intercept of the straight line corresponding to the velocity 2,060 m/sec is 0.063. Therefore, $0.063 = 2\times(2{,}060^2/415^3)(1-\cos^3 i)$, and hence $1-\cos^3 i = 0.533$; $\sin^3 i = 0.253$; and finally $y=(2{,}060/415)^3(0.253)=30.6$ meters.

As a basis for comparison, the computation was also performed assuming a linear variation of velocity. The parameters V_0 and h could have been found by comparing Figures 19 and 20, but the alternate method was used. From the point $x=40$ m, $t=0.069$ sec, a tangent to the dromochrone was traced (see Fig. 20). It was found that $\lambda=1.435$, hence by interpolation on Table I, $\xi=1.495$ $\tau=1.1915$;

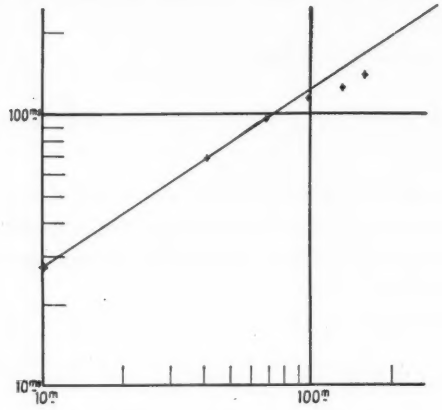

FIG. 19. Bi-logarithmic diagram of experimental data (Mont Cenis).

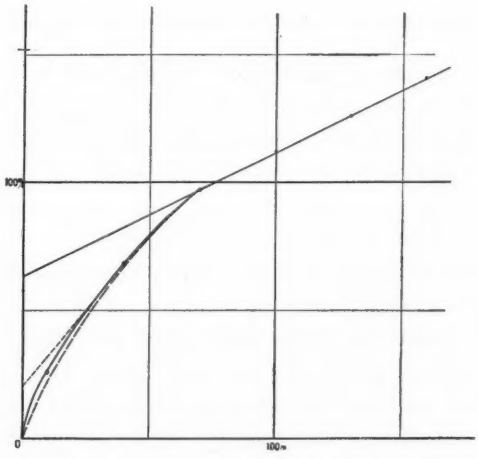

FIG. 20 Dromochrone for Mont Cenis shooting.

$h=x/\xi=13.4$ m; $V_0/h=17.3$; and $V_0=464$ m/sec. The curve plotted using these parameters passes well below the first point (0.021 instead of 0.026 sec).

The computation of the second layer is as follows

$$T_2 = 0.063 = (1/17.3)(\psi(464/2{,}060) - \psi(V_1/2{,}060))$$

$\psi(464/2{,}060)=1.195$ (Table I) and, by difference $\psi(V_1/2{,}060)=0.105$

$V_1/2{,}060=0.785$ (Table I) and thus $V_1=1{,}615$; $V_1/V_0=1{,}615/464=3.48 \doteq 1+y/h$; $y=33$ meters.

Thus, although the representation of the dromochrone is not as accurate as when using the relationship $V=k\sqrt[3]{y}$, the result is not too different. The computation is still somewhat longer than when this law is used, but yet it is about as rapid as when the alluvia are represented by two constant speed layers, which yields too low a result.

Consider now a relationship such that the velocity would start from zero at the surface and tend toward a limit as the wave penetrates deeper and deeper. For example, $V=A\sqrt{y/(y+h)}$.

It is obvious that two types of seismic rays must be considered whether $V/\sin i=\mu A$ is smaller ($\mu<1$) or greater ($\mu>1$) than the velocity limit A. If $\mu<1$ the ray is refracted and reaches back the surface. If $\mu>1$, the ray does not get back to the surface, except if it reaches a higher velocity medium, but tends toward an asymptotic direction such that $\sin i=1/\mu$.

The general equations lead to:

$$x=\int_0 \frac{y\,dy}{\sqrt{(\mu^2-1)y^2+\mu^2hy}}, \tag{33}$$

$$t=\frac{\mu}{A}\int \frac{(y+h)\,dy}{\sqrt{(\mu^2-1)y^2+\mu^2hy}}, \tag{34}$$

or, putting $x=\xi h$; $y=\eta h$; $t=(h/A)\tau$

$$\xi=\int_0 \frac{\eta\,d\eta}{\sqrt{(\mu^2-1)\left[\eta^2+\eta\mu^2/(\mu^2-1)\right]}}, \tag{35}$$

$$\tau=\mu\int_0 \frac{(1+\eta)\,d\eta}{\sqrt{(\mu^2-1)\left[\eta^2+\eta\mu^2/(\mu^2-1)\right]}}. \tag{36}$$

The dromochrone has to be constructed only when $\mu<1$. Then

$$\xi=\frac{1}{\sqrt{1-\mu^2}}\int_0 \frac{\eta\,d\eta}{\sqrt{\eta\mu^2/(1-\mu^2)-\eta^2}}, \tag{37}$$

$$\tau=\frac{\mu}{\sqrt{1-\mu^2}}\int_0 \frac{(1+\eta)\,d\eta}{\sqrt{\eta\mu^2/(1-\mu^2)-\eta^2}}. \tag{38}$$

The limits of these integrals are $\eta=0$ and $\eta=\mu^2/(1-\mu^2)$ (ray horizontal), and the values obtained should be doubled in order to get the length of apparent path and the travel time to the point where the ray returns to the surface.

Hence $\xi=\pi\mu^2(1-\mu^2)^{-3/2}$ and $\tau=\pi\mu(2-\mu^2)(1-\mu^2)^{-3/2}$

Table IV indicates values of ξ and τ for a series of points on the dromochrone. Figure 21 respresents a plot of the dromochrone on logarithmic paper, and a

TABLE IV

DROMOCHRONE FOR VELOCITY-DEPTH RELATIONSHIP $V=A\sqrt{(y)/(y+h)}$
FORMULAS: $\xi=\pi\mu^2/(1-\mu^2)^{3/2}$ $\tau=\pi\mu(2-\mu^2)/(1-\mu^2)^{3/2}$

ξ	τ	ξ	τ	ξ	τ
0.00378	0.216	1.215	4.26	15.16	22.8
0.01520	0.431	1.435	4.68	18.70	27.0
0.03450	0.665	1.712	5.19	23.65	32.7
0.06210	0.884	2.065	5.83	30.00	39.9
0.09820	1.112	2.440	6.43	39.00	49.9
0.14420	1.362	2.890	7.20	51.50	63.6
0.20200	1.620	3.450	8.23	69.15	82.4
0.26750	1.875	4.120	9.00	96.20	111.2
0.34800	2.140	4.840	10.03	138.00	153.5
0.44000	2.420	5.770	11.30	208.00	226.5
0.55300	2.740	6.940	12.85	334.00	352.0
0.67300	3.035	8.370	14.65	578.00	609.0
0.82500	3.405	10.130	16.81		
1.00400	3.810	12.350	19.62		

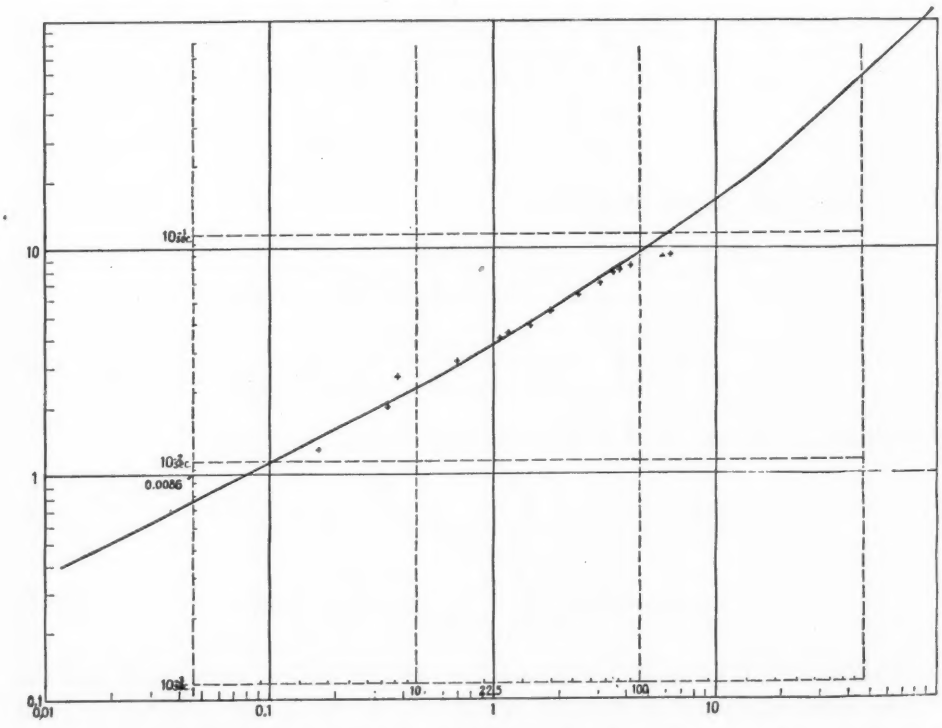

FIG. 21. With coordinates in full, theoretical diagram for relationship $V=A\sqrt{y/(y+h)}$. Dotted lines are related to experimental diagram, which should be drawn on transparent paper, and checked against theoretical one. When they fit together, position of axis shows values of parameters, here $h=22.5$ m and $h/A=0.0086$ sec.

simple translation would give a dromochrone for any value of h and A. Conversely these parameters can be determined from experimental points.

The thickness of the variable velocity layer overlying a constant velocity layer remains to be determined. This corresponds to a straight line portion of the dromochrone, and its intercept on the time axis is T_2. For the seismic ray which gets back to the surface after refraction in the constant velocity layer, $\mu = V_2/A$.

If x, y and t are the coordinates of the point where the ray reaches the interface,

$$T_2 = 2(t - x/V_2) = 2(h/A)(\tau - \xi/\mu) \tag{39}$$

and

$$\tau - \xi/\mu = \int_0^{\eta} \frac{(\mu + \eta(\mu^2 - 1)/\mu)d\eta}{\sqrt{(\mu^2 - 1)[\eta^2 + \eta\mu^2/(\mu^2 - 1]}}. \tag{40}$$

A change of variable $\eta = (1-s)\mu^2/(2-\mu^2)$ gives: if

$$\mu < 1 \quad \tau - \xi/\mu = (\mu/2\sqrt{1-\mu^2})(\arccos s + \sqrt{1-s^2}) = (\mu/2\sqrt{1-\mu^2})F(s), \tag{41}$$

if

$$\mu = 1 \quad \tau - \xi/\mu = \tfrac{1}{2}\sqrt{\eta}, \tag{42}$$

if

$$\mu > 1 \quad \tau - \xi/\mu = (\mu/2\sqrt{\mu^2-1})[\log(s+\sqrt{s^2-1}) + \sqrt{s^2-1}] = (\mu/2\sqrt{\mu^2-1})G(s) \tag{43}$$

The value of $F(s)$ and $(G(s)$ against $1-s$ and $s-1$, respectively, will be found in Table V. y is given by the relation $y = h(s-1)\mu^2/(2\mu^2-2)$.

If in the computation of the thickness of the following layers, y and μ are known, these tables will give immediately that portion of the delay measured by the intercept which is due to the travel in the first layer, exactly as in the cases previously considered.

As an illustration, these equations will be applied to a set of data obtained by E. R. Shepard (1939) at Whitney Point, N. Y. These data plotted on logarithmic coordinates (dotted lines) are shown on Figure 21. A dromochrone is plotted on the same figure and shown by solid lines. When the dromochrone is brought as close as possible to the experimental points, the relative positions of the axis gives immediately $h = 22.5$ m, $h/A = 0.0086$ sec, hence $A = 2{,}620$ m/sec. On the other hand, the end of the dromochrone plotted on cartesian coordinates is a straight line whose slope indicates a velocity $V_2 = 4{,}380$ m/sec and whose intercept is $T_2 = 0.055$ sec. Thus $\mu = 4{,}380/2{,}620 = 1.94$ and $\mu/(2\sqrt{\mu^2-1}) = 0.583$; $\tau - \xi/\mu = T_2A/2h = 3.2 = 0.583\ G(s)$. Hence $G(s) = 5.49$. By interpolating on Table V it becomes $s - 1 = 2.657$, and $y = 40.6$ meters.

Using the classical method Shepard (1939) found the thickness to be 35.2 m, and a nearby core drill test found the bed rock at 38 meters.

TABLE V

VELOCITY-DEPTH RELATIONSHIP $V=A\sqrt{(y)/(y+h)}$

$\mu = V_2/A$ $\qquad T_2 = (2h/A)(\tau - \xi/\mu)$

$\mu < 1$	$\mu > 1$
$\tau - \xi/\mu = \dfrac{\mu}{2\sqrt{1-\mu^2}} F(s)$	$\tau - \xi/\mu = \dfrac{\mu}{2\sqrt{\mu^2-1}} G(s)$
$y = \dfrac{h\mu^2}{2(1-\mu^2)}(1-s)$	$y = \dfrac{h\mu^2}{2(\mu^2-1)}(s-1)$
$F(s) = \arccos s + \sqrt{1-s^2}$	$G(s) = \operatorname{Log}(s+\sqrt{s^2-1}) + \sqrt{s^2-1}$

$F(s)$	$1-s$	$G(s)$	$s-1$
0	0	0	0
0.0350	0.00015	0.9013	0.1
0.0698	0.00061	1.2790	0.2
0.1047	0.00137	1.5875	0.3
0.1396	0.00244	1.8470	0.4
0.1744	0.00381	2.2964	0.6
0.3481	0.01520	2.6850	0.8
0.5206	0.03410	3.0490	1.0
0.6911	0.06030	3.3840	1.2
0.8589	0.09370	3.7020	1.4
1.0236	0.13400	4.0070	1.6
1.1845	0.18080	4.3070	1.8
1.3409	0.23400	4.5900	2.0
1.4925	0.29290	5.2830	2.5
1.5387	0.35720	5.9360	3.0
1.7790	0.42640	6.5750	3.5
1.9132	0.50000	7.1920	4.0
2.0408	0.57740	8.3980	5.0
2.1614	0.65800	9.5640	6.0
2.2749	0.74120	10.7090	7.0
2.3811	0.82640	11.8320	8.0
2.4797	0.91290	12.9420	9.0
2.5708	1.00000	14.0440	10.0
		15.1360	11.0
		17.2950	13.0
		19.4350	15.0
		21.5500	17.0
		23.6630	19.0

A certain amount of interpretation is possible in the way the experimental diagram fits the theoretical curve, but it does not affect the result materially. For example, in the illustration given above, an approximation that $h=36$ m and $A/h=0.0115$ would lead to a thickness of $y=43.1$ m, which is very close to the result just obtained.

The different types of velocity-depth relationship which have been reviewed correspond to logarithmic diagram either straight or concave downwards or upwards. They will probably suffice to represent about all experimental data. Eventually, the indicated results should be completed by computing values corresponding to slopes other than 2/3 or 1/2.

For each survey, or even for each kind of overburden, the type of velocity-

depth relationship which gives the best results may be chosen once and for all. When this choice is made, the computations pertaining to different profiles can be conducted very easily and, aided by the use of tables, they will not be longer than by the classical method, which requires the calculation of the thicknesses of two or three fictitious layers having a constant velocity.

The method which takes into account the variation of velocity in alluvia is closer to actual conditions, and therefore should lead to more accurate results. It gives a better understanding of what actually occurs. In particular, it will avoid the tempting association of successive constant speed layers to actual geologic layers. It is not even too daring to hope that it will be possible to work out a correlation between the type of velocity depth-relationship and the physical characteristics of the alluvia.

BIBLIOGRAPHY

Ewing, M., and Don Leet. "Comparison of Two Methods for Interpretation of Seismic Time-Distance Graphs Which Are Smooth Curves," *AIME Geophysical Prospecting* (1932), p. 263.

Shepard, E. R. *The Military Engineer*, XXXI, no. 179 (1939), 377, Fig. 13.

THE TELLURIC METHOD OF PROSPECTING AND ITS LIMITATIONS UNDER CERTAIN GEOLOGIC CONDITIONS*

V. S. TUMAN†

ABSTRACT

This paper is in four parts: Part one, deals with general considerations of geophysical methods. Part two briefly mentions the properties of the telluric field, and the telluric method. In part three, some simple problems are discussed, and as a result of the discussion, two factors are introduced: (A) The tectonic factor, ϕ, which is a function of the geology of the area. It could neither be measured, nor easily calculated; but only estimated roughly from the shape and the orientation of the ellipses. (B) The distorting factor Ψ which is a function of the physical properties of the beds. Its value could only be calculated, when the thicknesses of the beds, and their resistivity are known at the point of the measurements. In part four, it is concluded, that these factors set a limit in correlating the surface measurements to the actual shape and the size of the structure, and thus a limit to the interpretation of the results of a telluric survey.

INTRODUCTION

So far there is no single geophysical method which is ideal for the purpose of prospecting. Each one has its limitation and can be applied, but to only particular problems. In general, geophysical methods of prospecting can be classified into two categories:

(a) those in which natural fields are used for the purpose of prospecting;

(b) those in which an artificial field or energy source is produced to enable the prospecting to be carried on.

In the latter we have the power to control the quality and the quantity of the field. Whereas such power of control is lacking in the first type of prospecting methods. To produce an artificial field is obviously costly, and thus the second type of prospecting is more expensive than those in which the field is provided by nature.

The telluric method of prospecting falls into the first category, since the telluric field is a natural phenomenon. Evidently there is no depth control in this method. If the area under investigation is of a complicated nature, the picture derived at the surface is complex, the main geological features being distorted, and its analysis into the true structure is difficult and often impossible. This is not a special feature of this method, but also can be applied to other natural methods, i.e., the gravity and the magnetic methods.

There is much to be said in favor of the seismic methods, e.g. the refraction method, where frequently one can pick up a particular bed with a specific velocity of seismic wave propagation. Even such a method fails to distinguish two beds which have completely different structures, but have the same velocity of

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seismic wave propagation. For example, in the refraction seismic survey carried out in the Market Drayton, England a refracting horizon of 17,000 feet per second velocity was detected. This was followed for some 20 miles from east to west, and in this interval the refracting velocity changed very little. However, in the area there exist numerous faults. The upper Carboniferous rocks have been noticed at the surface as an outcrop due to the faulting. Also from the geology of the area, it is known that elsewhere Carboniferous Limestone exists. *Is the refracting horizon Carboniferous Limestone?* Holes drilled on two "highs" in the area revealed a pre-Cambrian basement of rhyolite at one point, while Carboniferous Limestone, of about 250 feet thick was encountered at the second point. In reality none of the geophysical methods provide nonambiguous solutions, unless they are related to bore hole evidence. This procedure is unfortunately very costly but it has become a standard practice.

TELLURIC FIELD, AND THE TELLURIC METHOD OF PROSPECTING

In this method of geophysical prospecting, advantage is taken of the existence of extensive sheets of current concentrated mainly in the conducting sediments. They flow over a large portion of the earth crust. The method differs from ordinary resistivity prospecting, the normal method most closely related to it, in that the effective current electrodes producing the current can be assumed to be at infinity, and the source of the electric field energy is supplied by nature.

The main earth's electric field covers a very large area of many thousands of square miles. These main earth currents are the result of many phenomena, such as rotation of the earth through the magnetic field of electric currents in the ionosphere, magnetic storms, etc. On these main earth currents, which vary in magnitude, are superimposed currents of local nature arising from numerous causes. The existence of these local currents makes the correlation of two records of natural earth potentials taken at two points separated by large distances, difficult and sometimes impossible.

At a point, in or at the surface of the ground, there is a potential gradient, changing its magnitude and direction continuously with time. Variation of this potential gradient with time is defined, for practical prospecting purposes, as the "*telluric field.*" The recordings upon which the experiment is based enables one to detect the projection, or the independent component, of the telluric field along a given direction i.e., the line joining the electrodes on the surface of the ground. By recording along two perpendicular directions, it is possible to compute the telluric field. In practice one examines the telluric field at a point, S, and the corresponding field at a point, B.

It has been shown by Schlumberger, and others that:

(A) If at a given moment the telluric field at a point, B, has a given magnitude and direction represented with a vector v, then at the same moment at any other points S it will have a magnitude and direction V. Because of superposition of the effect it follows that a vector kV at B, will correspond to a vector kV at S,

i.e. there is a linear relation between the two vectors. Two vectors are said to be "homologous," when there is a linear relation between them. Thus two vectors v and V are "homologous."

(B) If it is assumed that the telluric field at base B rotates in all directions, and consider the telluric vector as a unit, then it will produce a circle of unit radius and area π. Homologs of these vectors at any observation stations, S, will trace an ellipse. The shape and the area of these ellipses is a constant, independent of the direction of the lines on which the recording is made.

For a survey, simultaneous recordings are made at a base station, B, and an observation station, S. This process is repeated for numerous observation stations, say S_{a1}, S_{a2}, S_{a3}, $S_{a4} \cdots S_{an}$. The ellipse's area of stations, $S_{a1}S_{a2}S_{a3}S_{a4}S_{a5} \cdots S_{an} \cdots$ are computed. Depending on the extent of the survey, numerous base stations, are established, and finally all the stations $S_{ap}S_{am}S_{fq} \cdots S_{kn}$ etc., are connected to one base station. It is also customary to determine the homologous vectors at every station relative to the north and the east vector at a base station. By joining these vectors to one another, a map of the current flow in two perpendicular directions in the conducting beds is obtained. Such a map is of great significance, as it reveals the secret of the underlying beds, in the area which is investigated. Using other information such as electrical sounding profiles, along with the above map a contour map of equal area of ellipses is drawn.

For further detailed informations on the method and the computation of the results, the reader is referred to the references listed at the end of the paper. It is proposed in the remainder of the paper to investigate some simple problems encountered in the telluric survey, and the limitations of correlating the surface measurements with the dimensions and the shape of the structure.

SOME THEORETICAL CONSIDERATIONS

One Layer Problem.

The ideal case for investigation by the telluric survey involves a layer of sedimentary rock with fairly mild tectonics overlying a resistive bed rock, such as igneous rocks.

Assuming that

$$\rho_{\text{sed}} \ll \rho_{\text{igneous}}$$

then the telluric current density will be much greater in the sedimentary bed. Further it is reasonable to assume, particularly in the presence of a minimum of topographic relief in the basement, that little interchange of current will occur between the two formations. Thus the lower bed may be regarded as of infinite resistivity.

The integral $\int cds$ over any equipotential surface between the two boundaries of the bed is accordingly constant, where c is the total current density and ds an element of area of the equipotential surface, or

$$\int cds = \text{constant}. \tag{1}$$

Furthermore, in general we can write

$$\int c_n ds = \int cds = I = \text{constant}, \tag{2}$$

where I can be defined as the total current passing through any surface, where

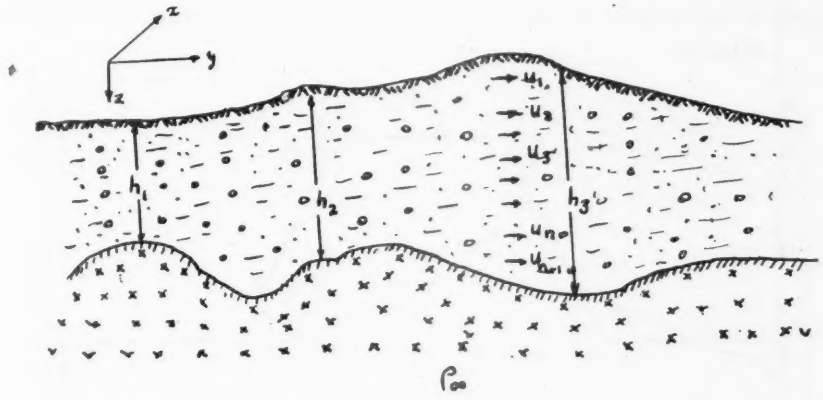

FIG. 1. One layer problem, when a sedimentary bed is lying on an infinite resistive bed.

c_n is the normal component of the current density over any vertical plane. Hence over the vertical xz plane

$$\int c_n ds \equiv \iint udxdz = I \tag{3}$$

where u is the component of the current density in the y direction. Let us assume a bed with thickness varying in the y direction only, i.e., a two dimensional problem. Then we can write

$$\int_x^{x+D} \int_0^h udxdz = \text{constant} = I, \tag{4}$$

where h is the thickness of the bed and D is the width of the section considered. Integrating we get in general

$$h_1u_1D = h_2u_2D = \cdots = h_nu_nD \tag{5}$$

$$h_1u_1 = h_2u_2 = \cdots = h_nu_n \tag{6}$$

where u is current density in the direction of y and is the projection of current density c on the y axis.

Equations (1) and (2) are equations of continuity and are perfectly general. However, in integrating these equations it has been assumed that u is independent of depth, and thus on this basis the equations (5) and (6) have been derived. If the thickness of the conducting layer is large compared with the electrode separation which is used to measure the surface potential gradient, and $\partial z/\partial y$ the slope of the bed is fairly small, i.e., up to 30 degrees, then it will be approximately independent of the depth. These statements are the results of

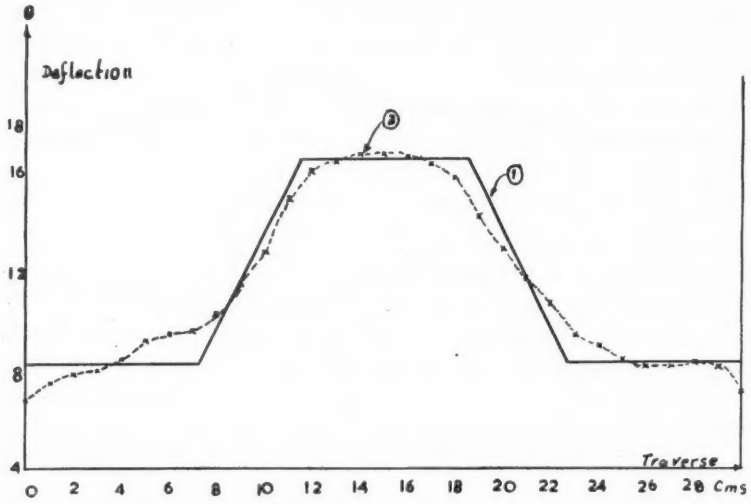

FIG. 2. Results of tin foil experiments. These are ideal two dimensional problems having various shapes. Curve (1) is the theoretical curve while Curve (2) is the actual plotting of the potential gradients measured at the surface of the structure.

some laboratory experiments carried out on tin foil. Under such ideal conditions it can be assumed that u remains constant over a particular vertical surface, i.e.,

$$u_1' = u_2' = u_3' = \cdots = u_n'. \tag{7}$$

From equation (6) we have

$$h_1/h_2 = u_2/u_1. \tag{8}$$

Where u_1 and u_2 are the current densities at sections where the depths are h_1 and h_2 respectively.
Also,

$$u_1 = -1/\rho_1/\partial v_1/\partial y \tag{9}$$

$$u_2 = -1/\rho_2/\partial v_2/\partial y, \tag{10}$$

whence,

$$\mu_1/\mu_2 = (1/\rho_1)/(\partial v_1/\partial y)/(1/\rho_2)(\partial v_2/\partial y). \tag{11}$$

If we are dealing with a homogeneous medium then

$$\rho_1 = \rho_2, \tag{12}$$

and finally

$$h_1/h_2 = (\partial v_2/\partial y)(\partial v_1/\partial y). \tag{13}$$

Therefore if the potential gradient along a profile in the y direction is measured,

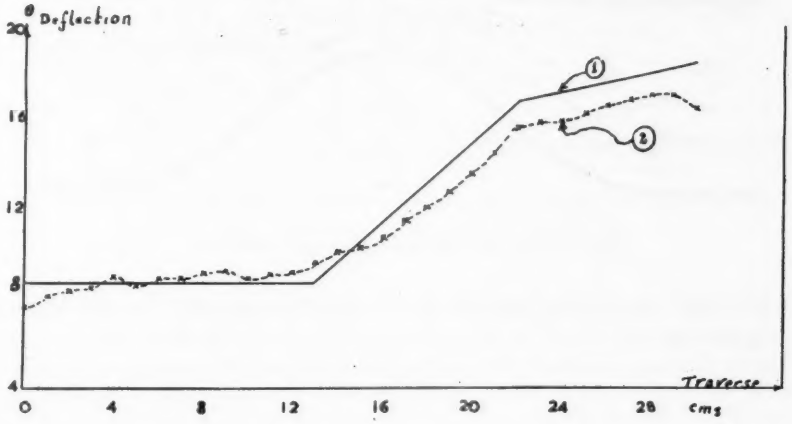

FIG. 3. Results of tin foil experiments. These are ideal two dimensional problems having various shapes. Curve (1) is the theoretical curve while Curve (2) is the actual plotting of the potential gradients measured at the surface of the structure.

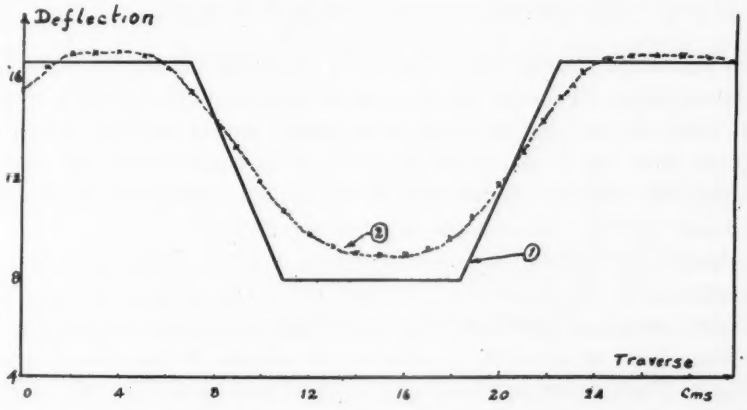

FIG. 4. Results of tin foil experiments. These are ideal two dimensional problems having various shapes. Curve (1) is the theoretical curve while Curve (2) is the actual plotting of the potential gradients measured at the surface of the structure.

by plotting gradients $\partial v/\partial y$ against y, and taking into account the surface topography, we obtain an approximate shape of the surface of the non-conducting basement. It is apparent that the type of current flow considered above is identical with flow in a thin conducting sheet of uniform thickness.

Experiments carried out with tin foil cut into different shapes have been used as small scale ideal structures, each with a different value of $\partial z/\partial y$. One can see immediately that these experiments justify the above discussion. The diagrams show two curves of which (1) is the theoretical curve of $1/h$ against y while (2) is the experimental curve of $\partial v/\partial y$ against y. In the field a difficulty arises due to

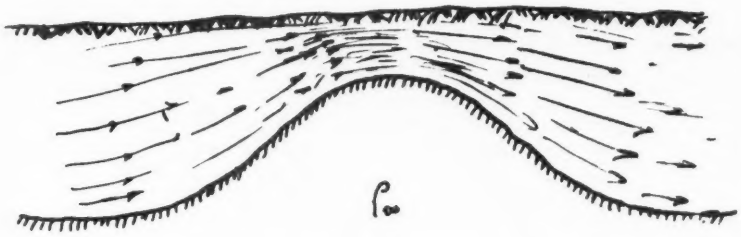

FIG. 5. Cross section of a cylindrical structure.

the fact that the conducting beds are not "two dimensional." In fact h is a function of x and y or

$$h = f(x, y). \tag{14}$$

To take this into consideration a tectonic factor ϕ is introduced. It is a factor whose value will be unity only for ideal cylindrical structure so that in general for a one layer case one can write

$$(\partial v_1/\partial y)/(\partial v_2/\partial y) = e_1/e_2 = h_2/h_1(\phi). \tag{15}$$

Thus a reasonably satisfactory theory is available for the interpretation of the simple one layer structure. Deviations of any formation from a cylindrical structure, when the tectonic factor ϕ is not unity, would tend to distort the derived picture from the true picture. It is in these cases where the axes of the ellipses, applying elliptical properties of the telluric field, and their directions relative to one another, prove to be of great significance.

In a cylindrical structure the potential gradients are variable for a current flowing perpendicular to the strike, but are uniform in the strike direction. This follows since the current always distributes itself over a constant cross section. Therefore an ellipse built at a point, S, relative to a base, B has a very important characteristic. *There would be a relatively constant axis in the direction and magnitude of the strike, while the variable axis is perpendicular to the strike.*

If in an area the axes of ellipses are all parallel to one another, then this is an indication that the structure is approximately cylindrical. *It is in such a struc-*

ture that the ratio of the two ellipses is approximately the same as the inverse ratio of the thickness of the conducting bed. In general the direction, and the magnitude of the two axes give an indication of the structure. The factor ϕ is a function of the direction in which the surface measurements are made. For a complete revolution, its value may change between 0.5 and 2. There are no means by which the value of ϕ could be measured or even calculated (*unless the dimensions of the structure are known in detail*). Only an approximate value for its magnitude could

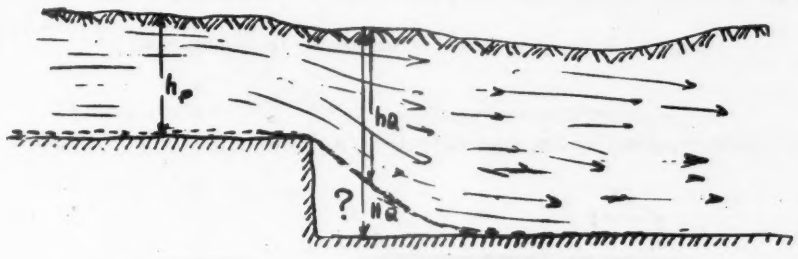

FIG. 6. Cross section of a faulted structure, where the picture derived at the surface along one traverse is very misleading.

be estimated for specific directions from the dimensions and the shape of the ellipse. As the number of layers increases, the effect produced by the tectonic factors ϕ multiplies, and thus their distortion effect on the surface measurements becomes more significant.

Two Layer Problem.

Assume two sedimentary beds of thickness h_1 and h_2 and resistivity ρ_1 and ρ_2 lying on an infinite resistive basement. If the structure has calm tectonics, $\partial h/\partial y$, or $\partial(hn+hm)/\partial y$ are moderate, we can say that $\partial v/\partial y$ or e the electrical field at the surface is approximately proportional to the inverse conductance c when,

$$c = h/\rho_\xi = hn/\rho_1 + hm/\rho_2, \tag{16}$$

where ρ_ξ is the resistivity of a bed of thickness h giving the same conductance c. Let

$$(\partial v/\partial y)_1 = e_1 = -\rho_1 u n_1 \tag{17}$$

$$(\partial v/\partial y)_2 = e_2 = -\rho_1 u n_2. \tag{18}$$

At the boundary the tangential potential gradients are continuous, i.e.,

$$\left.\begin{aligned} \rho_1 u n_1 &= \rho_2 u m_1 \\ \rho_1 u n_2 &= \rho_2 u m_2 \end{aligned}\right\} \tag{19}$$

Also, we have assumed that total current I remains constant in the conducting beds, therefore,

$$h_1u_1 = hn_1un_1 + hm_1um_1 = hn_2un_2 + hm_2um_2. \tag{20}$$

From equations (19) and (20)

$$e_1/e_2 = un_1/un_2. \tag{21}$$

Using equation (19) to eliminate um_1 and um_2 from Equation (20),

$$un_1hn_1 + (\rho_1/\rho_2)un_1hm_1 = un_2hn_2 + (\rho_1/\rho_2)un_2hm_2, \tag{22}$$

or,

$$un_1/un_2 = (\rho_2hn_2+\rho_1hm_2)/(\rho_2hn_1+\rho_1hm_1) = (hn_2/\rho_1+hm_2/\rho_2)/(hn_1/\rho_1+hm_1/\rho_2). \tag{23}$$

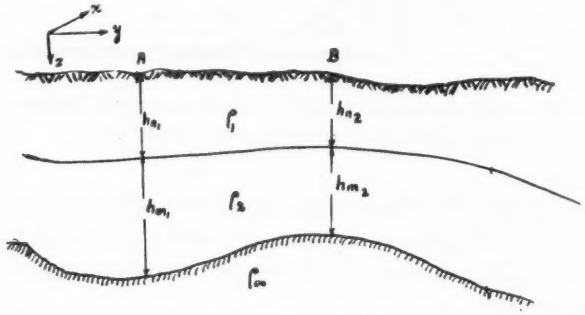

FIG. 7. Two layer problem. Here two sedimentary beds are lying on an infinite resistive basement.

Hence from Equation (21)

$$e_1/e_2 = (hn_2/\rho_1+hm_2/\rho_2)/(hn_1/\rho_1+hm_1/\rho_2). \tag{24}$$

In the single one layer case we had,

$$e_1/e_2 = h_2/h_1(\phi). \tag{25}$$

In the two layer case, equation (24) can be written as

$$e_1/e_2 = h_2/h_1(\psi)\cdot(\phi_{12}), \qquad \text{where} \qquad \{\phi_{12} = (\phi_1)\cdot(\phi_2)\} \tag{26}$$

Where,

$$\psi = h_1(\rho_2hn_2 + \rho_1hm_2)/h_2(\rho_2hn_1 + \rho_1hm_1). \tag{27}$$

Since the magnitude of factor ψ (Equation 27) will be considerably different from unity, its effect in distorting the actual picture derived from the ratios of potential gradients is significant, even when ϕ_{12}, the Tectonic factor is a unity. For this reason ψ *may be called the distorting factor*, and its influence will vary from station

to station. Thus the picture derived from these observation stations will not be affected uniformly. In the simple two layer case,

$$hn_1 = 2 \qquad hn_2 = 1 \qquad hm_1 = 1 \qquad hm_2 = 2, \tag{28}$$

so that

$$h_1 = h_2, \tag{29}$$

at the two points 1 and 2.
The value of ψ is a function of ρ_1 and ρ_2 only.

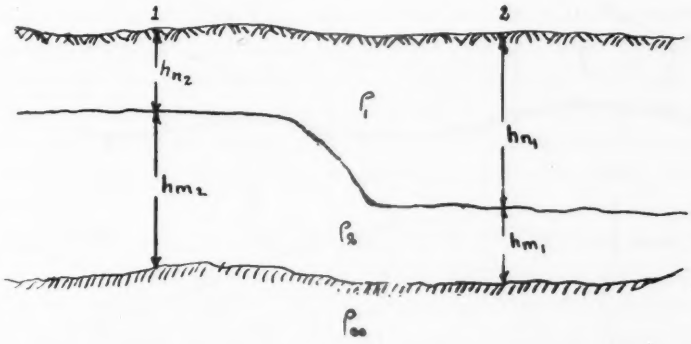

FIG. 8. To calculate the Distorting Factor a special two layer case is chosen. In this case the depth from the surface of the ground to the infinite resistive bed is assumed to be equal. $hn_1 = 2$, $hm = 1$; $hn_2 = 1$, $hm_2 = 2$, therefore $h_1 = h_2$.

Three Layer Problem

Assume three conducting layers, lying on a very resistive basement. This can be treated in a similar way using the boundary conditions by,

$$\left.\begin{aligned} \rho_1 un_1 &= \rho_2 um_1 = \rho_3 up_1 \\ \rho_1 un_2 &= \rho_1 um_2 = \rho_3 up_2 \end{aligned}\right\} \tag{30}$$

or,

$$\therefore \qquad \left.\begin{aligned} um_1 &= \rho_1/\rho_2\, un_1 \\ up_1 &= \rho_1/\rho_3\, un_1 \\ um_2 &= \rho_1/\rho_2\, un_2 \\ up_2 &= \rho_1/\rho_3\, um_2 \end{aligned}\right\}. \tag{31}$$

Again,

$$e_1/e_2 = un_1/un_2. \tag{32}$$

We have assumed that the continuity of the total current gives,

$$\left.\begin{aligned} h_1u_1 &= hn_1un_1 + hm_1um_1 + hp_1up_1 = I \\ h_2u_2 &= hn_2un_2 + hm_2um_2 + hp_2up_2 = I \end{aligned}\right\}. \tag{33}$$

From these it follows that,

$$un_1/un_2 = e_1/e_2 = (hn_2\rho_2\rho_3 + hm_2\rho_1\rho_3 + hp_2\rho_1\rho_2)/(hn_1\rho_2\rho_3 + hm_1\rho_1\rho_3 + h\rho_1\rho_1\rho_2) \tag{34}$$

and the distorting factor, ψ, is given by,

$$\psi = h_1[hn_2\rho_2\rho_3 + hm_2\rho_1\rho_3 + hp_2\rho_1\rho_2)/(h_2(hn_1\rho_2\rho_3 + hm_1\rho_1\rho_3 + hp_1\rho_1\rho_2)). \tag{35}$$

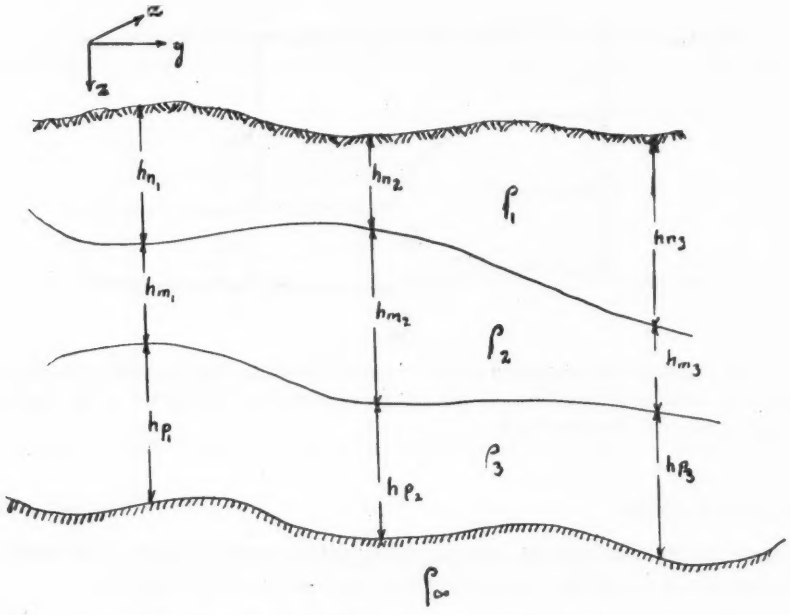

FIG. 9. Three layer case similar to one and two layer case.

This system of equations can be extended to any number of layers, leading to,

$$e_1/e_2 = un_1/un_2 = (hn_2\rho_2\rho_3\rho_4 \cdots \rho_\xi + hm_2\rho_1\rho_3\rho_4 \cdots \rho_\xi + \cdots h_{\xi_2}\rho_1\rho_2 \cdots \rho_\xi)$$
$$/(hn_1\rho_2\rho_3\rho_4 \cdots \rho_\xi + hm_1\rho_1\rho_3\rho_4 \cdots \rho_\xi + \cdots h_{\xi_1}\rho_1\rho_2 \cdots \rho_{\xi-1}), \tag{36}$$

with a distorting factor, ψ,

$$\psi = h_1/h_2\,(hn_2\rho_2\rho_3\rho_4 \cdots \rho_\xi + \cdots + h_{\xi_2}\rho_1\rho_2 \cdots \rho_{\xi-1})$$
$$/(hn_1\rho_2\rho_3\rho_4 \cdots \rho_\xi + \cdots + h_{\xi_1}\rho_1\rho_2 \cdots \rho_{\xi-1}) \tag{37}$$

where h_1 and h_2 are the total thickness at points 1 and 2 of all the layers. It is

evident that the complexity of ψ increases with the number of layers but factors of the order of magnitude of that already calculated are still to be anticipated.

CONCLUSIONS

It is evident that the two factors ϕ and ψ set a limit to the significance of the surface measurements in a telluric survey. The effect introduced by these two factors is large and complex where the thickness of the conducting sediments is considerable, and the number of layers numerous, thus the telluric picture derived at the surface is greatly distorted. This is specially so when the resistivity of these beds alternates with a large ratio, and the structures vary considerably from a cylindrical form. Therefore, results obtained from such a survey are of a qualitative nature only, and their significance cannot be correlated with the thickness and exact shape of the sediments. For this reason the telluric method of geophysical exploration is by no means superior to the seismic methods of prospecting. It is to be noted that in an effort to improve the interpretation, resistivity surveys are frequently carried out to yield information concerning the resistivitv changes involved.

When compared with the seismic method, it will be seen that the telluric method has, in fact, revealed areas of structural highs, although there are certain discrepancies in precise position. On the other hand the depth estimates are not reliable. It should be noted, however, that the telluric method is not claimed to be superior to the seismic method, but rather it can, under suitable conditions, give a clearer picture than the gravity and magnetic methods. On the assumptions made, the telluric procedure does not reveal resistivity changes in the basement, but only those in the superincumbent sediments. The gravity and magnetic methods, however, respond to all deep seated contrasts and the local effects are imposed upon the regional anomalies. In many cases the two effects are difficult to separate. The precise evidence yielded by the telluric method is one of the magnitude of the surface resistivity and current density, and the problem to be solved in the interpretation, is to determine the relative significance of these factors. If the two could be separated from the measurements by satisfactory supplementary experiments, then a more accurate picture might well be determined.

ACKNOWLEDGMENTS

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BIBLIOGRAPHY

Anales de Geophysique, Vol. 2 (1946).
Fleming, *Terrestrial Electricity and Magnetism* (A valuable chapter on the earth currents by Rooney).
Geophysical Union 20th Annual Meeting, 1939.
Geophysics, January 1942.
Geophysics, October 1945.
Geophysics, July 1948.
Tuman, V. S., "A General Survey of the Telluric Method of Geophysical Prospecting," Unpublished Thesis, Imperial College, London University.

ELECTRIC LOGGING APPLIED TO GROUND-WATER EXPLORATION*

P. H. JONES AND T. B. BUFORD†

ABSTRACT

A method is described for the determination of the quality of ground water in granular aquifers penetrated by rotary-drilled holes electrically logged. Conventional techniques of electric-log interpretation, to determine true bed resistivity from apparent resistivity values, are briefly described; and a method for converting water-resistivity values into hypothetical chemical analyses is explained.

The objective of the method is to narrow the limits of error in quality-of-water estimates based upon electric logs. Water-well contractors are fully aware of the risks attendant in making drill-stem tests in open hole, which is the method now employed to obtain representative samples of formation water. Packer failure results in contaminated samples; hole collapse may mean loss of drill stem, screen, and the hole. In the Gulf Coast where water-well tests range in depth from 100 to 3,000 feet, methods that will eliminate at least a part of the need for drill-stem tests deserve consideration. The paper deals also with methods of determining formation porosity *in situ*, which is an important factor in salt-water-encroachment problems.

INTRODUCTION

Quantitative interpretation of resistivity data obtained from electric logs has been possible in the United States only during the past decade, during which the fundamental interpretive equations have been derived and applied. The electric log now serves not only as a graph or "picture" of the resistivity profile of the rock sequence penetrated by the bit, valuable for correlation of the formations from hole to hole, but also as a physical measurement of their thickness, porosity, and fluid content. The oil industry has been concerned largely with the oil-gas and oil-water relationships in the sands, rather than the chemical character of the waters. Application of the electric-logging technique to ground-water exploration is in its early stages, from the standpoint of quantitative results.

It is a simple matter to obtain true resistivity of thick granular aquifers from the electric log, and it is possible to determine the physical characteristics of the sands that influence bed resistivity by testing formation samples, i.e., drill cuttings, carefully collected from small-diameter rotary-drilled wells. The resistivity of the water that fills the voids in the sand can then be calculated.

The resistivity of a water has a definite relation to its chemical content. Pure water is essentially a nonconductor, and the amount of ionized mineral matter in solution determines its resistivity. Thus the electrical resistivity of a water, which is determined at standard temperature and pressure, indicates the degree to which mineral matter is present.

If the ions of all salt solutions were equally mobile and carried the same electri-

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cal charge it would be rather simple to interpret water resistivity in terms of total ion concentration. However, this is not true, and it is not practicable to attempt interpretation of resistivity data for a water solution in parts per million of dissolved solids unless the "family" of mineral salts that may be present is predictable, at least in a general way. Fortunately, from the standpoint of ground-water exploration, a given aquifer generally is characterized by a certain assemblage and relative concentration of mineral salts in water, at least within a certain area. This is generally true, not only for a single aquifer, but also for several aquifers in the same geologic formation. Where there is marked change in the lithologic or structural conditions, however, the character of the chemical constituents of the water may be expected to differ. On a regional basis, formations of great lateral extent and limited thickness, composed of from one-third to two-thirds of sand, may be expected to yield ground water having a characteristic chemical quality. Change in chemical quality with distance from the outcrop, the area of ground-water recharge, generally follows a determinable pattern, and must be recognized in quantitative interpretation of water-resistivity data.

The writers gratefully acknowledge the advice and assistance generously given by Mr. Hubert Guyod of the Well Instrument Developing Company, and Mr. R. T. Wade of the Schlumberger Well Surveying Corporation. Constructive criticism and suggestions with regard to techniques were received from Mr. Nicholas A. Rose, consulting ground-water geologist, and Mr. W. W. Hastings, Chemist, U. S. Geological Survey. Mr. Leo W. Hough, State Geologist of Louisiana, through his interest in this study, has assisted materially in its completion. The investigations leading to this paper were conducted under the general supervision of Mr. V. T. Stringfield, Senior Geologist, and Mr. A. N. Sayre, Chief, Ground Water Branch, U. S. Geological Survey.

DETERMINATION OF TRUE RESISTIVITY FROM THE ELECTRIC LOG

The true resistivity of a bed is determined from measured apparent resistivity by simultaneous application of two corrections, one for relative thickness and one for relative apparent resistivity. The relative thickness is obtained by dividing the bed thickness by the electrode spacing. The relative apparent resistivity is obtained by dividing the maximum apparent resistivity in sand by the average resistivity in shales. The correction factor to apply to obtain true resistivity can be read from a chart prepared by Guyod (1943). This procedure should be followed only for beds whose thickness is less than or equal to electrode spacing.

If bed thickness ranges from more than once to less than twice the electrode spacing no method of analysis gives reliable results. The only solution is to use a different electrode spacing. This is one of the reasons why electric logs are generally made with two or three different electrode spacings, giving at least one usable resistivity curve for each bed.

If bed thickness is greater than twice electrode spacing no correction factor

need be determined. A reliable value of true resistivity may be obtained by graphical analysis of the log, as follows:

1. Select on the resistivity curve for the aquifer, points of maximum inflection on the curve, drawing horizontal lines through these points.
2. Pick on the resistance curve the point P, exactly half way between the lines. The apparent resistivity at this point is very close to the true resistivity of the bed, provided, as is usually true, that the aquifer resistivity is not too high.

Resistivity-departure curves that enable determination of true resistivity of thick formations have been prepared by the Schlumberger Well Surveying Corp. (Doll, 1947). It is necessary to know the following four values to determine true resistivity of the bed: (1) the electrode spacing, (2) the hole diameter, (3) the resistivity of the drilling mud, and (4) the apparent resistivity of the bed. Guyod (1947–48) has described a variety of conditions in which use of the departure curves gives information that could not be obtained in any other way.

FACTORS THAT AFFECT THE RESISTIVITY OF A GRANULAR AQUIFER

The electrical resistivity of a water-saturated granular aquifer is a function of its porosity and the distribution of the pores. Given constant water resistivity, formation resistivity is inversely proportional to porosity raised to an exponential power that represents void distribution. These relationships are expressed by the equation derived by Archie (1942).

$$Rt = Rw/P^m \qquad (1)$$

$$F = 1/P^m \qquad (2)$$

$$Rt = FRw \qquad (3)$$

where Rt = formation resistivity
Rw = water resistivity
P = porosity
m = cementation factor (void-distribution coefficient)
F = formation factor

The value of Rt, true formation resistivity *in situ*, is obtained from the electric log by the method explained in the first part of this paper. The water resistivity, Rw, can be determined by electrical test if a sample is available, or by calculation if formation samples, sand, are available in addition to the electric log. Porosity values can be measured by volumetric test of formation samples or cores; or they can be calculated if Rt, Rw, and the coefficient m are known. The void-distribution coefficient m, commonly termed the cementation factor, can be determined by electrical test in the laboratory, using formation samples of known porosity saturated with water of known resistivity, at constant temperature.

Table 1 gives the results of laboratory tests of 62 sand samples from aquifers of Tertiary, Pleistocene, and Recent age. Porosities ranged from 24.9 to 50.1 per cent. The greatest range occurred among samples from the Fleming formation,

a name used by the Louisiana Geological Survey, of Miocene age. Angularity and arrangement of grains, uniformity of texture, and cementation since deposition determine the porosity.

TABLE 1

PHYSICAL CHARACTERISTICS OF FORMATION SAMPLES

USGS well	Sample depth (feet)		Porosity (per cent)	Formation factor (Rt/Rw)			Cementation factor	
				(From elec. log & water resistivity)	(By lab. test)		(By lab. test)	
	(Top)	(Bottom)			Test 1	Test 2	Test 1	Test 2
Wilcox formation (Eocene)								
Na-53	212	221	43.3	3.53	3.69	3.75	1.55	1.59
Na-53	221	231	40.0	3.53	3.80	—	1.50	—
Na-55	674	682	40.3	4.35	2.88	3.48	1.15	1.41
Na-57	556	567	41.3	4.16	3.70	4.40	1.58	1.64
Na-57	567	577	41.4	4.16	3.90	5.00	1.55	1.58
Na-57	577	587	41.8	4.16	4.30	4.64	1.57	1.77
Na-58	506	516	43.0	3.72	4.17	4.56	1.57	1.93
Na-58	527	538	41.3	3.72	3.80	4.84	1.57	1.96
Na-61	535	545	40.1	2.43	3.70	4.90	1.46	1.93
Na-61	545	556	43.9	2.43	3.20	4.20	1.40	1.82
Sparta sand (Eocene)								
Na-54	359	370	39.0	3.71	3.61	3.58	1.39	1.60
Na-58	260	274	44.5	1.29	3.80	4.05	1.54	1.68
Na-61	217	250	39.9	7.05	3.86	2.90	1.52	1.15
Ou-100	644	656	40.3	3.55	4.00	3.33	1.60	1.33
Ou-100	656	667	42.9	3.55	3.90	3.23	1.65	1.37
Ou-101	707	714	43.8	2.65	4.05	2.75	1.72	1.20
Ou-102	223	235	43.5	4.50	3.40	2.60	1.45	1.13
Ou-102	362	373	46.4	3.44	3.30	3.45	1.52	1.60
Ou-102	466	478	43.9	3.62	3.50	3.00	1.55	1.30
Ou-102	488	497	40.7	3.62	3.50	3.16	1.40	1.27
Ou-102	705	729	33.7	3.99	5.80	5.00	1.93	1.65
Ou-103	504	528	44.0	2.51	4.40	3.22	1.93	1.40
Ou-103	712	736	46.5	3.55	4.30	3.80	1.97	1.75
Catahoula formation (Miocene)								
G-105	232	236	40.9	3.49	4.35	4.24	1.60	1.75
G-105	236	248	40.0	3.49	4.26	4.00	1.68	1.59
Fleming formation (Miocene)								
Al-108	1,738	1,761	38.8	3.59	4.60	4.00	1.63	1.54
Al-108	1,796	1,807	37.9	—	4.00	4.00	1.50	1.49
Al-108	1,807	1,818	39.6	—	4.36	4.30	1.70	1.61
Al-108	1,841	1,852	39.8	—	4.50	4.30	1.62	1.69
Al-109	516	526	31.3	2.83	4.25	4.25	1.23	1.23
R-432	346	354	46.44	2.49	2.13	3.33	0.97	1.53
R-432	354	364	43.73	2.49	2.58	3.04	1.10	1.31
R-432	364	376	50.06	2.49	3.06	3.23	1.50	1.61
R-432	458	468	43.00	1.31	4.36	4.66	1.85	1.99

TABLE 1—*Continued*

USGS well	Sample depth (feet)		Porosity (per cent)	Formation factor (Rt/Rw)			Cementation factor	
				(From elec. log & water resistivity)	(By lab. test)		(By lab. test)	
	(Top)	(Bottom)			Test 1	Test 2	Test 1	Test 2
Formations of Pliocene and/or Pleistocene age								
EB-444	2,012	2,043	40.4	—	4.00	2.60	1.60	1.04
EB-444	2,054	2,087	40.0	—	4.05	3.00	1.59	1.20
Ev-142	510	545	38.2	4.96	4.04	4.07	1.53	1.54
Ev-142	545	563	36.2	4.96	4.18	4.52	1.50	1.62
Ev-142	934	940	38.0	4.94	4.37	4.32	1.63	1.62
Ev-142	940	957	38.7	4.94	4.74	4.85	1.81	1.85
WBR-23	2,108	2,135	40.57	3.62	4.80	4.23	1.92	1.70
Formations of upper Pleistocene age								
JD-224	122	144	40.07	3.16	2.50	—	1.00	—
JD-224	144	166	36.20	2.97	3.21	—	1.15	—
JD-224	166	190	31.70	2.97	4.81	—	1.50	—
JD-224	212	234	29.55	3.46	6.78	—	1.95	—
JD-224	234	257	28.57	4.29	5.16	—	1.45	—
JD-224	257	274	27.18	2.64	5.71	—	1.52	—
JD-224	274	293	31.91	3.20	8.75	—	2.71	—
JD-224	302	323	24.88	3.30	6.25	—	1.52	—
JD-224	323	344	26.83	3.79	6.82	—	1.79	—
JD-224	344	365	32.30	4.78	8.18	—	2.59	—
JD-224	365	386	37.45	3.96	5.20	—	1.92	—
JD-224	386	407	40.14	3.63	3.40	—	1.35	—
JD-224	428	450	31.16	3.96	5.45	—	1.65	—
JD-224	450	465	33.04	3.79	5.21	—	1.70	—
JD-224	465	473	29.01	4.38	7.39	—	2.09	—
JD-224	495	510	30.84	—	6.25	—	1.89	—
JD-224	555	602	33.76	5.10	3.10	—	1.02	—
JD-224	602	647	35.70	2.92	3.62	—	1.28	—
JD-224	647	692	34.71	3.51	3.95	—	1.35	—
Formations of Recent age								
Na-54	77	84	36.4	4.03	3.30	3.48	1.20	1.72
Na-58	63	71	40.8	2.18	4.79	4.45	1.59	1.85

In his study of the water-bearing characteristics of granular rocks Slichter (1899), to resolve all variables in shape and arrangement of grains, first made a theoretical study of an "ideal soil" consisting of spherical grains of equal size. His description of the geometry of systematic packing in an "ideal soil" follows:

> If the grains of soil are arranged in the most compact manner possible, each grain will touch surrounding grains at twelve points, and the element of volume will be a rhombohedron having face angles equal to 60° and 120°. If the grains are not arranged in the most compact manner the rhombohedron will have its face angles greater than 60°, and each sphere will touch other spheres in but six points but will nearly touch in six other points. The most open arrangement of the soil grains which is possible with the grains in contact is had when the rhombohedron is a cube.

Graton and Fraser (1935) do not accept Slichter's postulate of the cube and "simple" rhombohedron (a rhombohedron each of whose faces is the "simple" rhomb of edge 2R) as special limiting cases of a general rhombohedron capable, by variation of its face angles to any intermediate value between the 90° and the 60°–120° of these limiting cases, of representing the equivalent of every possible variety of systematic packing between the cubic, or loosest, and the rhombohedral, or tightest. They state:

> This conception of an infinite series of possible "intermediate" rhombohedrons, each with a given porosity, as entertained by Slichter, helps undoubtedly to emphasize the inescapable effect of packing on porosity. But it would seem that such intermediate rhombohedral arrangements are, in the first place, less likely actually to occur in a natural assemblage of solid units; moreover, they seem more arbitrary, less varied, and therefore less general, less easy of visualization, and less enlightening than are the six cases here presented, . . . (which) are analogous to well known simple crystal forms; and finally, complete and exclusive commitment to this conception of a "general rhombohedron" leads to various real errors.

It has been demonstrated by the authorities here cited that a sand made up of perfect spheres with cubic packing has a porosity of 47.6 per cent. The same sand with orthorhombic packing has a porosity of 39.5 per cent; and with rhombohedral packing, 25.9 per cent according to Graton and Fraser (1935).

Laboratory measurements of porosity of sand samples may or may not be representative of their porosities *in situ*, but repeated determinations for the same samples gave comparable values, as shown in Table 2. It may be that the

TABLE 2

POROSITY DETERMINATIONS FOR SELECTED SAMPLES
(Expressed as per cent of sample volume)

USGS well no.	Sample depth (feet)		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Average porosity	Maximum departure from av.
	Top	Bottom								
Wilcox formation (Eocene)										
Na-55	662	673	39.73	40.07	40.62	40.63	40.36	40.28	40.28	−0.55
Sparta sand (Eocene)										
Ou-102	705	729	35.73	34.95	32.41	34.87	34.91	33.75	34.42	−2.01
Catahoula formation (Miocene)										
G-105	236	246	41.30	40.98	40.88	41.36	42.59	40.00	41.19	+1.40
Formations of Pliocene and/or Pleistocene age										
EB-444	2,012	2,043	40.89	40.82	40.58	41.35	40.95	40.40	40.83	+0.52
Sediments of upper Pleistocene age										
JD-224	555	602	33.53	32.85	32.19	32.89	32.40	33.76	32.94	+0.82
Sediments of Recent age										
Na-58	63	71	36.61	37.89	36.32	37.61	37.71	40.80	37.82	+2.18

degree of packing is subject to less variability for sands of non-uniform texture than for uniform-textured sands. However, irregularities in the shape of the grains composing the sand result in a wider possible range in porosity values and cross-sectional areas of voids because irregular forms may, theoretically, be packed either more tightly or more loosely than spheres.

Table 3 gives the porosities of grade-sized samples of sand. There is no orderly relation between porosity change and gradation in texture or change in permeability of the samples tested, but a systematic increase in both formation factor and cementation factor occurs with increase in coarseness of the texture of samples.

TABLE 3

PHYSICAL CHARACTERISTICS OF GRADE-SIZED SAMPLES

Passed by screen opening (inches)	Retained by screen opening (inches)	Porosity (per cent)	Permeability		Formation factor ($F=Rt/Rw$)	Cementation factor (m)
			(Meinzer's)	(Darcys)		
0.0344	0.0232	40.17	2,588	126.3	4.08	1.63
0.0232	0.0198	41.43	1,810	88.3	4.06	1.65
0.0198	0.0716	41.41	1,365	66.6	3.87	1.59
0.0716	0.0614	40.02	1,232	60.1	3.88	1.53
0.0614	0.0138	41.87	920	44.9	3.96	1.63
0.0138	0.0116	45.32	498	24.3	3.30	1.48
0.0116	0.0097	41.56	388	18.9	3.60	1.48
0.0097	0.0082	44.40	276	13.5	3.10	1.37
0.0082	0.0058	42.37	204	9.9	3.00	1.26

The graphs in Figure 1 show the relation among the porosity, the formation factor, and the cementation factor of a sand. Rapid determination of the approximate porosity of a sand can be made from this chart if the electric log, the water

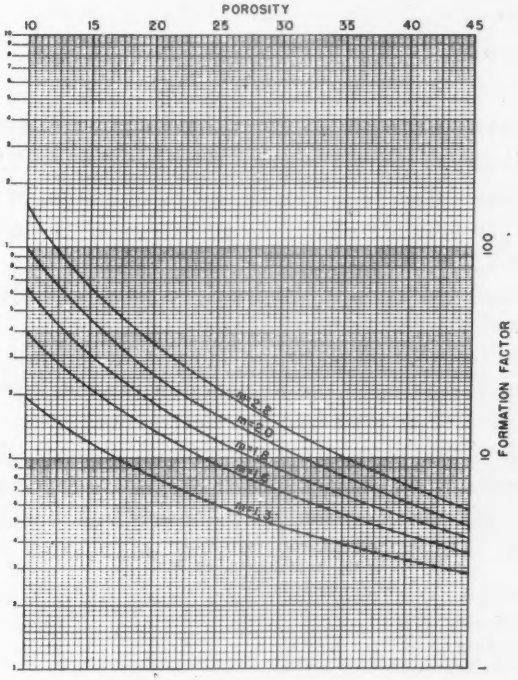


FIG. 1. Graphs showing relation among porosity, cementation factor, and formation factor.

resistivity, and the cementation factor are known. The method is applied in the fourth part of this paper.

With regard to the coefficient m, which he terms the porosity exponent, Jones (1946) states:

> The value of m depends upon length of (ion travel) path and distribution of voids. If the voids in media are distributed uniformly, m depends on the length of the tortuous path through which a current is displaced. The length of the tortuous path for rhombohedrally-packed well-sorted media (sand) is on the order of 1.3. The length of the path in fractured (rock) and in (rock) having solution channels may be less than 1.3. The length of the tortuous path in consolidated (rock) is longer than 1.3 especially if the distribution of voids is not uniform.

Calculations based upon laboratory tests of 62 samples from unconsolidated fresh-water sands ranging in age from early Eocene to Recent showed an average value of m equal to 1.55. All samples were obtained as returns from rotary-drilled wells and were collected and tested by the authors. The average values of the m factor for tested samples of sand from the Tertiary formations of Louisiana ranged from 1.52 to 1.61. The m factor for 10 samples from the Wilcox formation averaged 1.61; for 13 samples from the Sparta sand, 1.52; for 11 samples from the Catahoula and Fleming formations, 1.53; for 7 samples of sand from beds of Pliocene and/or Pleistocene age, 1.43; for 19 samples of sand and gravel of upper Pleistocene age, 1.65; and for 2 samples from beds of Recent age, 1.59.

Reference to equation (3) shows that determination of formation-water resistivity from the electric log requires only a knowledge of the formation factor F. This can be determined by electrical test of drill cuttings from the formation in a resistivity cell, using an electrolyte of known conductance at constant temperature.

DERIVATION OF HYPOTHETICAL CHEMICAL ANALYSES FROM RESISTIVITY DATA

Ground waters always contain mineral salts in solution. The electrical resistivity of an aqueous solution of a mineral salt is a function of ion concentration and ion mobility. The mobility of an ion depends upon its molecular weight and its electrical charge. The resistivity of a water solution of a single salt varies inversely with the concentration of the dissolved solution, provided that the salt is completely ionized.

The resistivity of a solution of two or more salts depends upon the relative concentration of each, and upon the tendency of the ions to join to form more complex ions having greater mass and less electric charge.

Below is a table listing some of the compounds generally found dissolved in ground waters, followed by their approximate relative specific conductances, reciprocal of resistance, as compared to the specific conductance of sodium or potassium chloride.

Compound	*Relative specific conductance*
Sodium or potassium chloride (NaCl or KCl)	1.00
Sodium or potassium sulfate (Na_2SO_4 or K_2SO_4)	0.40
Calcium or magnesium sulfate ($CaSO_4$ or $MgSO_4$)	0.32
Sodium bicarbonate or potassium bicarbonate ($NaHCO_3$ or $KHCO_3$)	0.50
Calcium carbonate or magnesium carbonate ($CaCO_3$ or $MgCO_3$)	0.27

It is apparent from this table and the graphs shown in Figure 2 that considerable error in calculation of dissolved solids of water from resistivity data will result if no information is available with regard to the probable nature of the dissolved solids.

Generally ground water from a selected well tapping a single aquifer is nearly constant in chemical quality. The chemical constituents bear a rather definite relation to the mineral composition, texture, and structure of the aquifer; the distance of the well from the outcrop area, where the aquifer is exposed to recharge; and other factors, such as topography and climate, that determine the

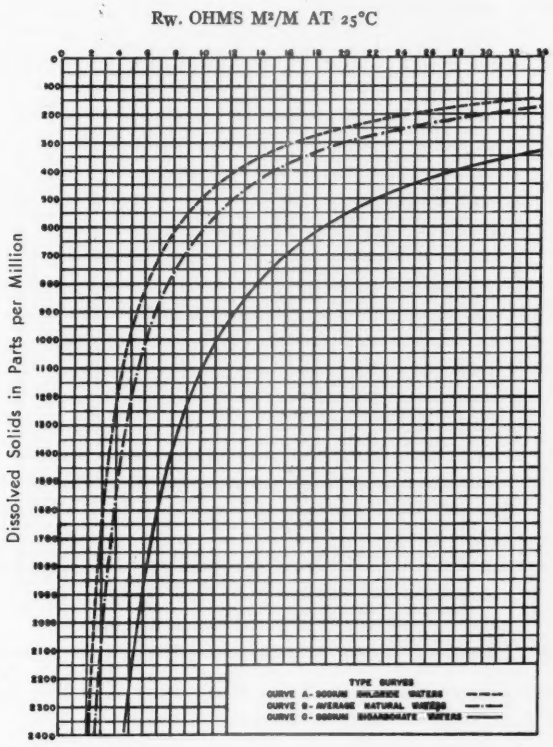


FIG. 2. Resistivity change with variation in dissolved solids; type curves.

rate of movement of the water. Sand aquifers of great areal extent and continuity often yield water that has a rather uniform chemical composition or a composition that changes uniformly with depth of occurrence or distance from the outcrop.

In most places, though not everywhere, there is a progressive increase with depth of occurrence in the amount of dissolved solids in ground water. The water from the upper Pleistocene sands of southwest Louisiana is commonly soft, low in dissolved solids, and acid in reaction near the outcrop. Down the dip it is hard,

contains a higher total of dissolved solids, and is alkaline in reaction. Still farther down the dip it is highly mineralized and impotable. The progressive increase in dissolved solids down the dip follows a rather systematic pattern with regard to changes in chemical composition. This is true of most extensive aquifers, or zones of aquifers, in a selected formation. *It is this systematic change in the "family" of ions present, with change in total dissolved solids, that enables interpretation of water-resistivity measurements in terms of dissolved solids, and in probable concentration of the important chemical constituents.*

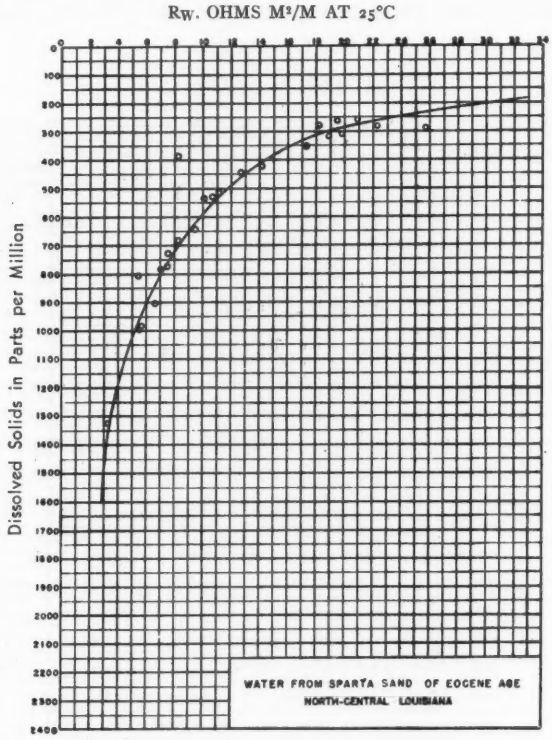


FIG. 3. Resistivity change with variation in dissolved solids; water from Sparta sand of Eocene age, north-central Louisiana.

To demonstrate this, curves have been prepared showing the relation between the electrical resistivity and the dissolved-solids contents of waters from each of the important water-bearing formations of Louisiana. Figures 3, 4, and 5 are examples. The curves are not hypothetical, but actual plots based upon chemical analyses and electrical-resistance measurements made in the laboratories of the U. S. Geological Survey. Curves are based on all analyses of water from the selected formations. No analyses were deleted because they did not "fit the picture." Figure 2 shows curves for three general types of natural waters. The wide divergence in the quantity of dissolved solids one might interpret from

these curves, with a given resistivity determination, is graphically shown. For example, a resistivity of 10 ohm-meters might mean that the water contains about 490 parts per million of dissolved solids, if it were a sodium chloride water; or the water might contain about 1,115 parts per million of dissolved solids if it were a sodium bicarbonate water. An error of this magnitude would place severe limitations on the usefulness of the resistivity determination as a key to the nature of the water. However, under natural conditions the range of error is

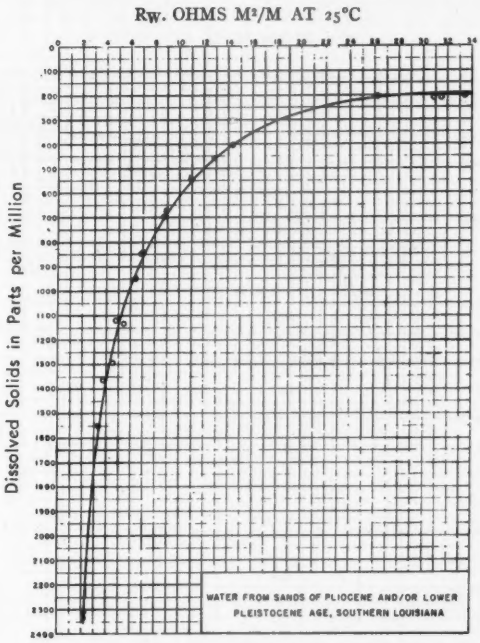

R_W. OHMS M^2/M AT 25°C
Dissolved Solids in Parts per Million
WATER FROM SANDS OF PLIOCENE AND/OR LOWER PLEISTOCENE AGE, SOUTHERN LOUISIANA

FIG. 4. Resistivity change with variation in dissolved solids; water from sands of Pliocene and/or lower Pleistocene age, southern Louisiana.

much narrower, for pure sodium bicarbonate or sodium chloride water is almost nonexistent.

It is to be noted that the widest margin of error occurs in the range most critical from the standpoint of water usability between dissolved solids contents ranging from about 300 to about 2,000 parts per million. A brief review of the drinking-water standards of the U. S. Public Health Service, and tables of suggested water-quality tolerances for selected industrial uses, would demonstrate quickly the need for a more accurate interpretive technique. Comparison of Figure 2 with Figures 3, 4, and 5 shows the relatively greater accuracy attained in making interpretations from curves plotted for each formation, based upon analyses of water from that formation. Comparison of the curves for the formations, one with the other, shows a remarkable similarity of slope and position, and indicates that curve B of Figure 2, for an "average natural water," applies

quite well for all the important water-bearing formations of Louisiana.

Use of the appropriate curve plot to interpret from resistivity data the dissolved solids content of water from a known formation source will give reasonably accurate values. However, the usefulness of a value for dissolved solids alone in determining the chemical quality of a water is of limited value in many instances. *The dissolved solids value should be interpretable in terms of the concentration of each important ion present.* To enable the preparation of a hypothetical

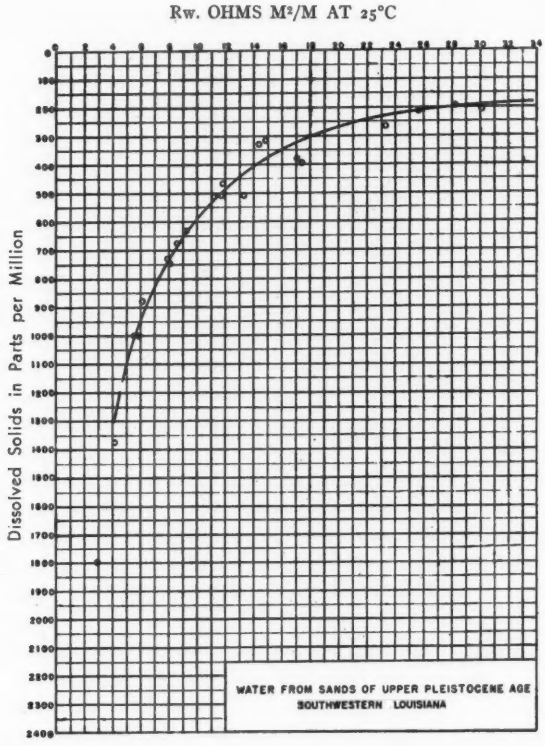

Rw. OHMS M²/M AT 25°C
Dissolved Solids in Parts per Million
WATER FROM SANDS OF UPPER PLEISTOCENE AGE
SOUTHWESTERN LOUISIANA

FIG. 5. Resistivity change with variation in dissolved solids; water from sands of upper Pleistocene age, south-western Louisiana.

chemical analysis of water from its electrical resistivity, a further step is required. Ion determinations for all available complete analyses of water from wells in Louisiana tapping each of the water-bearing formations described above are plotted on coordinate paper, with ion concentration the ordinate and the quantity of dissolved solids the abscissa. Analyses of 27 waters were used in the preparation of Figure 6, of 39 waters in the preparation of Figure 7, and of 23 waters in the preparation of Figure 8. Curves representing the change in concentration of ions with increase in the dissolved solids are drawn through the points. Although there is a scattering of points, there is an essential regularity to their distribution, and

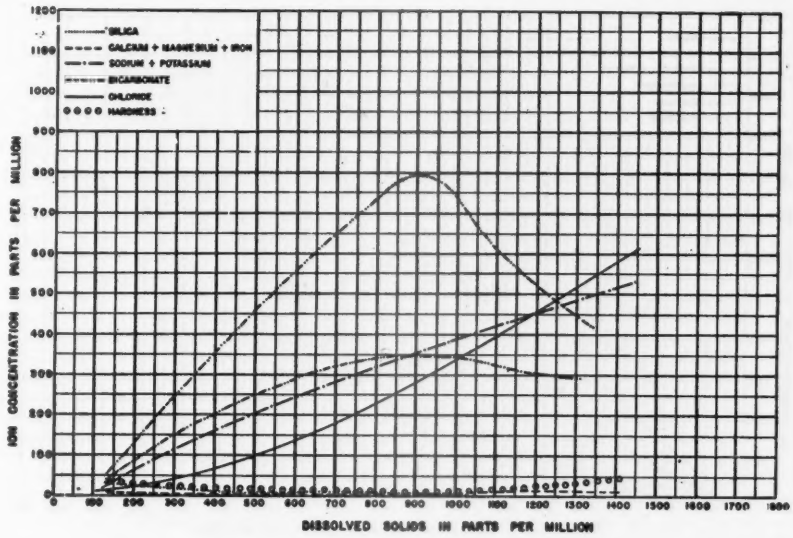


FIG. 6. Ion-concentration change with total dissolved solids; water from Sparta sand of Eocene age, north-central Louisiana.

relatively few points appear erratic. Use of the curves shown in Figures 6, 7, and 8, permits the derivation of an approximate hypothetical chemical analysis.

An application of the interpretive method described above will demonstrate its usefulness. Let us assume that a sample of water is obtained from each of

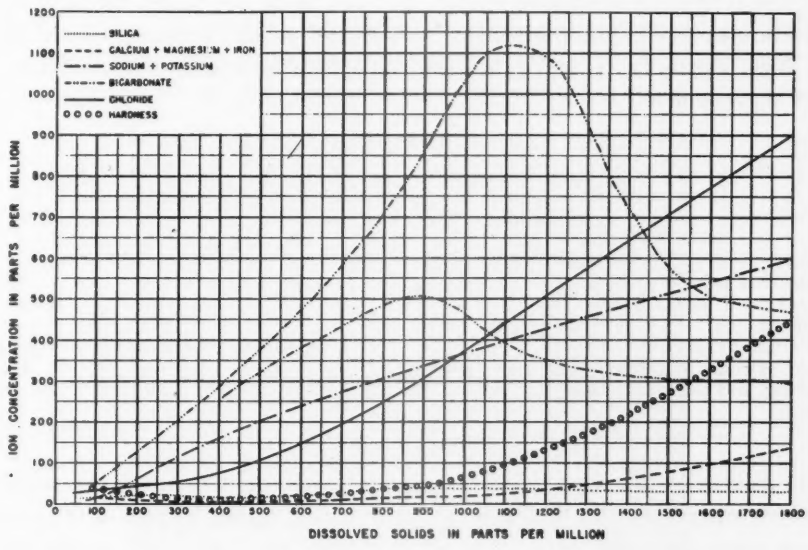


FIG. 7. Ion-concentration change with total dissolved solids; water from sands of Pliocene and/or Pleistocene age, southern Louisiana.

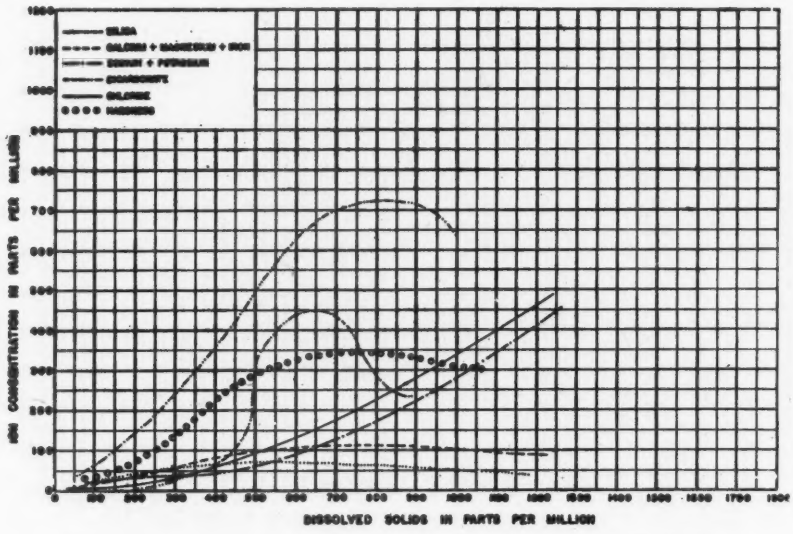


FIG. 8 Ion-concentration change with total dissolved solids; water from sands of upper Pleistocene age, south-western Louisiana.

three formations, sample A from an aquifer in the Sparta sand of Eocene age, sample B from an aquifer of Pliocene and/or lower Pleistocene age, and sample C from an aquifer of upper Pleistocene age. Let us assume further that the electrical resistivity of all three waters, determined from the electric log by application of the technique described above, is found to be the same; for example, 12 ohm-meters at 25°C. The quantities of dissolved solids for these waters are obtained from Figures 3, 4, and 5, and the concentrations of ion constituents from Figures 6, 7, and 8.

APPROXIMATE ANALYSES EXPRESSED AS PARTS PER MILLION

	Sample		
	A	B	C
Dissolved solids	500±	500	500−
Total hardness as $CaCO_3$	20	15	285
Chloride (Cl)	100	110	90
Bicarbonate (HCO_3)	250–450	350–450	200–500
Iron, calcium, and magnesium (Fe+Ca+Mg)	4	7	100
Sodium and potassium (Na+K)	200	200	60
Silica	12	38	75

The resistivity of water changes markedly with temperature, even within the range of temperature at which fresh ground waters occur. Effects of temperature changes upon the resistivity of a salt solution are illustrated graphically by Figure 9. For each bed under investigation the temperature of the rock materials and water *in situ* must be determined or closely estimated, and the calculated

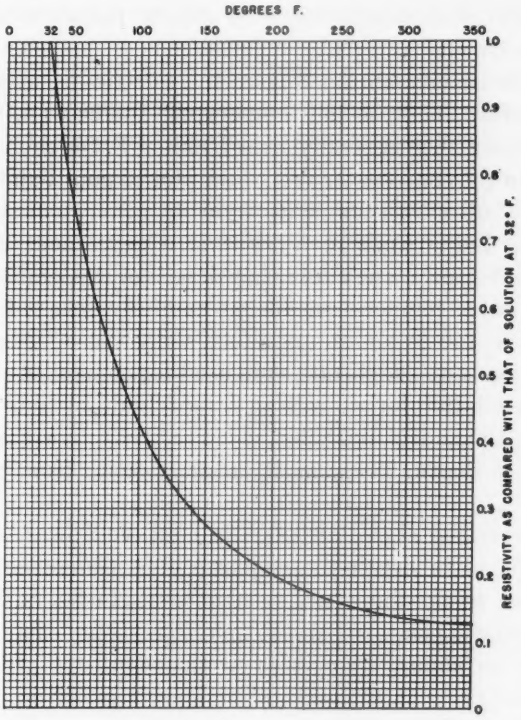


FIG. 9. Resistivity variation with temperature of a salt solution.

resistivity of the interstitial water at that temperature converted to its value at a standard temperature. Established practice is to express water resistivities at 25°C. for comparison and interpretation. Figure 10 is a resistivity-correction

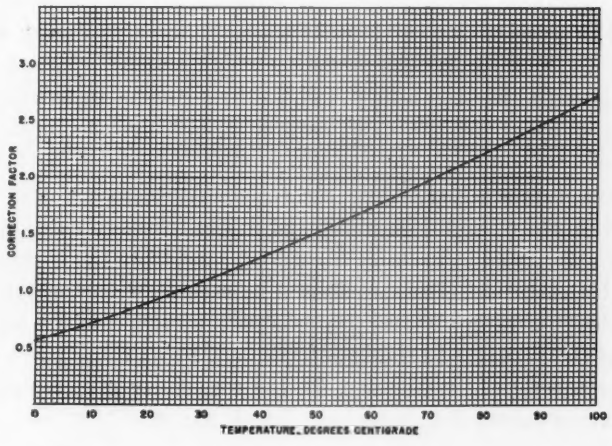


FIG. 10. Correction factor to convert resistivity at other temperatures to resistivity at 25° Centigrade.

chart showing correction factors to apply to convert resistivity of water at other temperatures to resistivity at 25°C.

Values of true resistivity obtained from the electric log must always be corrected for temperature, because the temperature increases with depth. In the Gulf Coast the temperature generally rises about 1°F. for each 70 to 100 feet of increase in depth, in the fresh-water section. A plot of points showing the relation between depth of aquifer and temperature of its water shows that in southern Louisiana, south of the latitude of Alexandria, the gradient is about 1°F. for each 90 to 100 feet of depth. The curve that describes this gradient is based upon measurements of water temperature for 71 carefully selected wells ranging in depth from less than 100 to about 3,000 feet. Only those wells tapping a single aquifer and discharging at a high rate were used for control. A similar plot of the depth-temperature relation for 29 wells in central and northern Louisiana, north of the latitude of Alexandria, describes a curve showing a gradient of 1°F. for each 65 to 70 feet of depth. These wells range in depth from 75 to about 1,300 feet.

Both curves described above are slightly concave upward, if plotted in the northeast quadrant, with depth the ordinate. The difference in the gradients may be attributable to age difference or structural effects. Satisfactory application of the interpretive method based upon resistivity determination in the borehole therefore requires a knowledge of the depth-temperature gradient in the area under study.

FIELD APPLICATION OF THE METHOD

The only formation samples generally available from water wells are drill cuttings. If these cuttings are obtained with a cable-tool rig they are likely to be representative of the formation penetrated and to give reliable results when tested. If the hole is made by hydraulic-rotary drilling much care must be exercised in their collection, but satisfactory samples can be obtained. The sand sample is tested in a resistivity cell similar to that shown in Figure 11. The sand sample is rinsed thoroughly in clear water to which a small amount of table salt or sodium bicarbonate has been added, two to three ounces in 10 quarts of water. Time should be allowed for the sand sample to become thoroughly saturated with an excess of test solution, and for the mixture of sand and test solution to reach atmospheric temperature. Then the resistivity of excess test solution decanted from the mixture should be measured in the resistivity cell. Immediately thereafter the resistivity cell should be filled with sand from the composite sample, saturated with test solution. The cup should be rapped with a spatula or similar tool to insure close packing of sand grains and the escape of air bubbles. Then the resistivity of the saturated sand is determined. From these two readings, Rw, resistivity of the interstitial water and Rt, the resistivity of the water-saturated sand, the formation factor F can be calculated, as:

$$Rt/Rw = 1/P^m = F \text{ (D. 117)}.$$

Several tests of fractions from the same sample will give values whose average should be very close to the formation factor of the sand.

Figure 11 taken from Guyod (1944) shows a bakelite tube five inches long and three inches in diameter having two current electrodes and two potential-measuring electrodes. C, one of the current electrodes, is a brass plate that forms the bottom of the cell. It is press-fitted in the bakelite tube. P_1 and P_2, the potential-measuring electrodes, are brass rings set 1 inch apart. They are placed between bakelite spacers S, S', and S'' in order to insure a uniform diameter for the column of water in the vicinity of the potential-measuring electrodes.

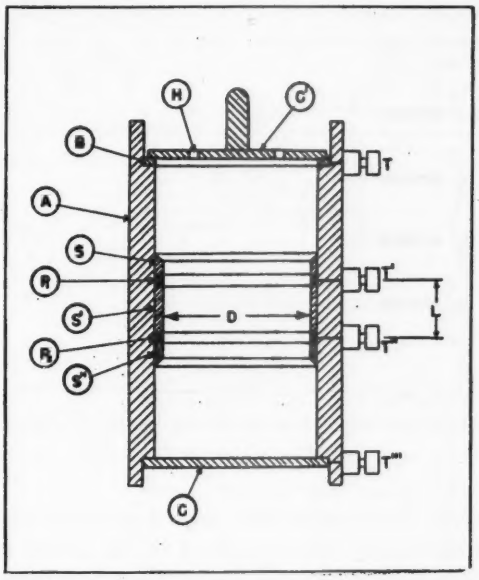


FIG. 11. Resistivity cell.

C', the second current electrode, is a brass plate resting on a brass ring, B. The purpose of ring B is to connect C' to the current source. Plate C' forms the removable lid of the cell. Several small overflow holes, H, are provided in this plate. B, P_1, P_2, and C are electrically connected to terminal posts T, T', T'', and T''', respectively. When the cell is filled with the solution to be tested, C and B are connected to a current supply, and the resulting potential difference V existing between P_1 and P_2 is measured with a voltmeter. The application of Ohm's law to the section of the circuit between P_1 and P_2 gives:

$$V = (Rw)(L)(I)/(A)$$

or,

$$Rw = (A)(V)/(L)(I)$$

where

Rw = the resistivity of the water (ohm meters),

V = the potential difference between P_1 and P_2 (volts),

I = the current flowing in the cell (amperes),

A = the inside cross-sectional area of the rings P_1 and P_2 (square meters),

L = the separation P_1, P_2 (meters)

A and L are measured only once; V and I are measured for each sample of water. In order to prevent introduction of errors due to polarization, alternating current should be used; 60-cycle current is suitable and generally available.

The wiring diagram, Figure 12, is that of a simple circuit that may be used

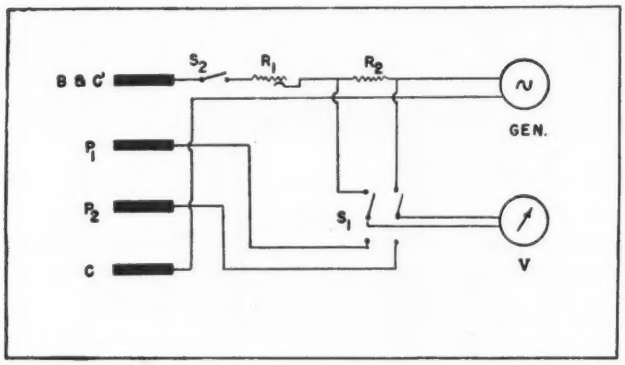


FIG. 12. Circuit arrangement for measuring resistivity of water and sand samples in the resistivity cell.

with the resistivity cell. The current used should be no more than 50 milliamperes and its duration of flow should be restricted to the actual time required for the test. Otherwise the sample would be heated and gas bubbles produced. Both these phenomena would affect the measurement. The current circuit consists of the source *GEN*, two resistors, R_1 and R_2, a switch S_2, and the two electrodes C and C': The circuit is closed through the water or water-saturated sand contained in the cell. R_1 is a variable resistor, and its value is large enough so that the current may be adjusted to about 10 milliamperes. The purpose of resistor R_2 is to provide a convenient method for determining the magnitude of the current I flowing in the circuit. This is done by measuring the voltage across R_2 and applying with an alternating-current voltmeter V of high internal resistance —1,000 ohms per volt, for example.

The resistivity cell used by the authors was the conventional mud-testing unit used by the Schlumberger Well Surveying Corp., which has point-type rather than ring-type potential electrodes. Modification of the cell to provide ring-type potential electrodes as described above no doubt would have given more consistent resistivity data for repeat tests of the same sands. Also, a larger cell would give better results—for best results the cell should contain perhaps

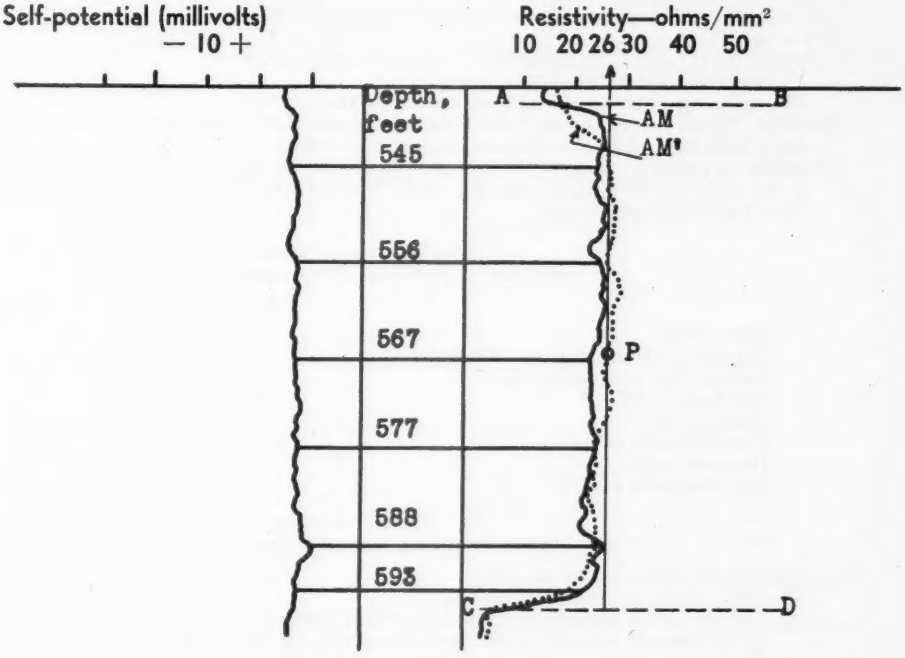
two to three quarts of test sample. Experiments should be conducted to determine the most satisfactory size. In the following pages the test procedure and interpretive method are applied to aquifers that occur in three of the principal water-bearing units of Louisiana.

EXAMPLE 1. SPARTA SAND (EOCENE)

Hole diameter: 6.25 inches
Mud nature: Natural
Mud weight: 12 lbs/gal
Mud viscosity: 35 sec
Mud resistivity: 7.0 ohm-meters at 50°F.
Total depth of hold: 991 feet
Bottom-hole temperature: 80°F.

USGS No. Na-57
Natchitoches, La.
December 11, 1943

Electrode separation for curves:
AM = 10 inches
AM′ = 39 inches



Data from electric log

Thickness of aquifer = 57 feet
Electrode spacing AM′ = 3.25 feet
True resistivity of aquifer (by graphic solution) = 26 ohms/$m^2m = Rt$
Temperature of aquifer = 76°F.

Data from formation samples

Sample depth (feet)	Porosity (per cent)	Resistivity-cell test results	
		Formation factor (F)	Cementation factor (m)
556–567	41.3	4.05	1.61
567–577	41.1	4.45	1.57
577–588	41.8	4.47	1.67

Mechanical analyses of sand fractions
(per cent of sample retained, by weight)

Sample depth (feet)	8–4 mm	4–2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.12 mm	0.12–0.06 mm	Uniformity coefficient
545–556			0.17	1.38	20.95	73.72	3.78	
556–567			.07	.30	12.80	82.31	4.52	1.92
567–577			.05	.46	24.43	72.54	2.52	2.53
577–588			.03	.16	31.52	64.46	3.83	2.41
588–593				.21	44.02	44.83	10.94	
593–595			.09	1.64	50.64	36.48	11.15	

Quality-of-water determination

As $Rt = FRw$ (equation (3) p. 117)
$Rw = Rt/F$ $Rw = 26/4.32$ (av.) $= 6.01$ ohms/m^2m at 76°F.
76°F. = 24.44°C.
To correct Rw at 24.44°C. to Rw at 25°C. (standard temperature):
From chart, figure 10, correction factor is 0.98.
$6.01 \times 0.98 = 5.88$ ohms/m^2m at standard temperature.
The graph, Figure 3, indicates that water from the Sparta sand with a resistivity of 5.88 ohms/m^2m has a dissolved-solids total of about 920 parts per million.
The graphs on Figure 6 enable preparation of a hypothetical chemical analysis of the water. Following is the hypothetical analysis, together with the actual chemical analysis of formational water from a well tapping the sand.

Chemical analyses of water
(expressed as parts per million except *Rw*)

	Hypothetical	*Actual*
Silica (SiO_2)	20	—
Calcium (Ca)+magnesium (Mg)+iron (Fe)	20	5
Sodium (Na)+potassium (K)	360	321
Bicarbonate (HCO_3)	350–790	262
Chloride (Cl)	290	347
Total hardness as $CaCO_3$	14	12
Dissolved solids	920	818
Rw, ohms/m^2m at 25°C.	5.88	5.46

Porosity determination
(from electric log and water analysis)

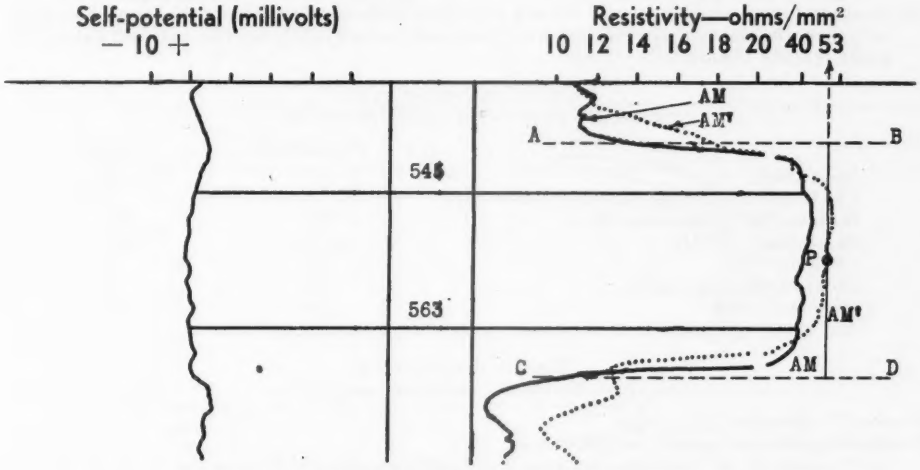
$Rt = Rw/P^m$ (equation (1), p. 117)
Physical conditions for aquifer, *in situ:*
(1) Convert *Rw* of formational water at standard temperature to *Rw* of water *in situ* (24.44°C.) 5.46 (from lab. analysis)/0.98 (from corr. chart, Fig. 10) = 5.58 ohms/$m^2m = Rw$
(2) $Rt = 26$ ohms/m^2m
(3) Cementation factor m, average for Sparta sands (p. 122) = 1.52
Then $26 = 5.58/P^{1.52}$, or $P^{1.52} = 5.58/26 = 0.214$
$P = \sqrt[1.52]{0.214}$; $\log P = \log 0.214/1.52 = 9.03304 - 10/1.52$
$= 9.3639 - 10$
P = antilog $9.3639 - 10 = 23.11\%$; laboratory value = 41.4

EXAMPLE 2. SAND OF PLIOCENE AND/OR PLEISTOCENE AGE

Hole diameter: 12 inches
Mud nature: Magcogel, clay
Mud weight: 12 lbs/gal
Mud viscosity: 60 sec
Mud resistivity: 6.5 ohm-meters at 85°F.
Total depth of hole: 1,002 feet
Bottom-hole temperature: 95°F. (?)

USGS No. Ev-142
Mamou, La.
May 11, 1948

Electrode separation for curves:
AM = 16 inches
AM′ = 64 inches



Data from the electric log

Thickness of aquifer = 32 feet
Electrode spacing AM′ = 5.3 feet
True resistivity of aquifer (by graphic solution) = 53 ohms/$m^2m = Rt$
Temperature of aquifer = 75°F.

Data from formation samples

Sample depth (feet)	Porosity (per cent)	Resistivity-cell test results	
		Formation factor (F)	Cementation factor (m)
510–545	38.2	4.06	1.54
545–563	36.4	4.35	1.56

Mechanical analyses of sand fractions
(per cent of sample retained, by weight)

Sample depth (feet)	8–4 mm	4–2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.12 mm	0.12–0.06 mm	Uniformity coefficient
510–545			0.04	0.44	45.87	51.73	1.92	
545–563		0.80	.11	10.43	71.63	16.57	.46	

Quality-of-water determination

As $Rt = FRw$ (equation (3) p. 117)
$Rw = Rt/F$ $Rw = 53/4.20 = 12.62$ ohms/m^2m at 75°F.
75°F. = 23.89°C.
To correct Rw at 23.89°C. to Rw at 25°C. (standard temperature):
From chart, Figure 10, correction factor is 0.97
$12.62 \times 0.97 = 12.24$ ohms/m^2m at standard temperature.
The graph, in Figure 4, indicates that water from sands of Pliocene and/or lower Pleistocene age with a resistivity of 12.24 ohms/m^2m has a dissolved-solids total of about 485 parts per million.
The graphs in Figure 7 enable preparation of a hypothetical chemical analysis of the water. Following is the hypothetical analysis, together with the actual chemical analysis of formational water from a well tapping the sand.

Chemical analyses of water
(expressed as parts per million except *Rw*)

	Hypothetical	*Actual*
Silica (SiO_2)	28	25.7
Calcium (Ca)+magnesium (Mg)+iron (Fe)	7	4.3
Sodium (Na)+potassium (K)	195	175
Bicarbonate (HCO_3)	310–370	366
Chloride (Cl)	105	45
Total hardness as $CaCO_3$	16	11.5
Dissolved solids	485	682
Rw, ohms/m^2m at 25°C.	12.24	—

Porosity determination
(from electric log and water analysis)

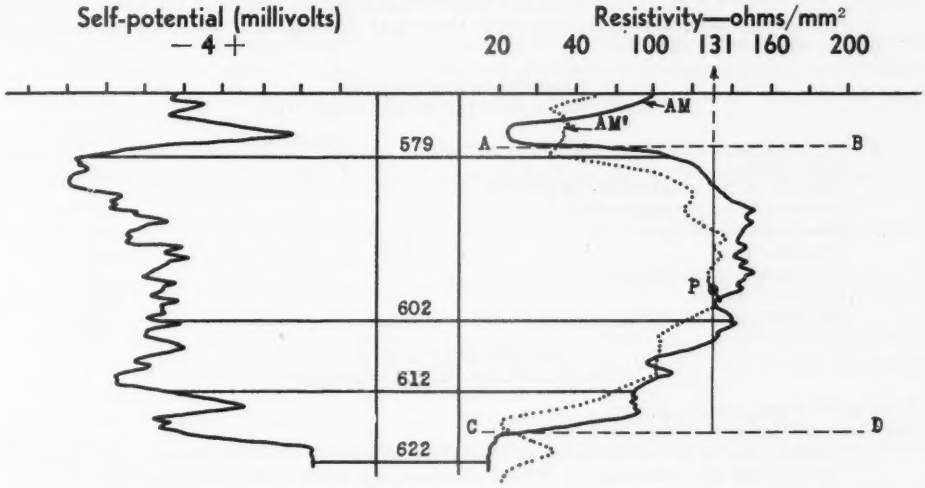
$Rt = Rw/P^m$ (equation (2), p. 117)
Physical conditions of aquifer, *in situ:*
(1) Convert *Rw* of formational water at standard temperature to *Rw* of water *in situ* (23.89°C.). (*Rw* not determined for this sample: use total dissolved solids of 682 and chart, Figure 4, to get *Rw* of 8.8 ohms/m^2m
8.8/0.97 (from corr. chart, Fig. 10) = 9.07 ohms/$m^2m = Rw$
(2) $Rt = 53$ ohms/m^2m
(3) Cementation factor m, average for sands of Pliocene and/or lower Pleistocene age (p. 122) = 1.43
Then $53 = 9.07/P^{1.43}$, or $P^{1.43} = 9.07/53 = 0.1711$
$P = \sqrt[1.43]{0.1711}$; log P = log 0.1711/1.43 = 9.02332 − 10/1.43
= 6.3100 − 6.993
= 9.3170 − 10
P = antilog 9.3170 − 10 = 20.75%; laboratory value = 37.3

EXAMPLE 3. SAND OF UPPER PLEISTOCENE AGE

Hole diameter: 5.5 inches
Mud nature: Natural
Mud weight: ?
Mud viscosity: ?
Mud resistivity: 8.3 ohm-meters at 67°F.
Total depth of hole: 757 feet
Bottom-hole temperature: 76°F. (est.)

USGS No. JD-224
Pine Island, La.
May 15, 1946

Electrode separation for curves:
AM = 16 inches
AM′ = 63 inches



Data from electric log

Thickness of aquifer = 40 feet
Electrode spacing AM′ = 5.25 feet
True resistivity of aquifer (by graphic solution) = 131 ohms/$m^2m = Rt$
Temperature of aquifer = 74°F.

Data from formation samples

Sample depth (feet)	Porosity (per cent)	Resistivity-cell test results	
		Formation factor (F)	Cementation factor (m)
555–602	33.76	3.10	1.02
602–647	35.70	3.62	1.28

Mechanical analyses of sand fractions
(per cent of sample retained, by weight)

Sample depth (feet)	8–4 mm	4–2 mm	2–1 mm	1–0.5 mm	0.5–0.25 mm	0.25–0.12 mm	0.12–0.06 mm	Uniformity coefficient
579–602		12.56	17.37	36.72	29.11	1.68	2.56	
602–612	.87	14.32	17.57	29.95	32.70	4.51	.08	
612–622			6.31	27.85	43.79	17.39	4.66	
622–647		13.84	19.18	31.35	31.52	3.80	.31	

Quality-of-water determination

As $Rt = FRw$ (equation (3) p. 117)
$Rw = Rt/F$ $Rw = 131/3.36 = 38.98$ ohms/m^2m at 74°F.
74°F. = 23.33°C.
To correct Rw at 23.33°C. to Rw at 25°C. (standard temperature):
From chart, Figure 10, correction factor is 0.96
$38.98 \times 0.96 = 37.42$ ohms/m^2m at standard temperature.
The graph, in Figure 5, indicates that water from the sands and gravels of Pleistocene age with a resistivity of 37.42 ohms/m^2m has a dissolved-solids total of about 180 parts per million.
The graphs in Figure 8 enable preparation of a hypothetical chemical analysis of the water. Following is the hypothetical analysis, together with the actual chemical analysis of formational water from a well tapping the sand.

Chemical analyses of water
(expressed as parts per million except Rw)

	Hypothetical	*Actual*
Silica (SiO_2)	42	39
Calcium (Ca)+magnesium (Mg)+iron (Fe)	30	28.7
Sodium (Na)+potassium (K)	30	42
Bicarbonate (HCO_3)	135	122
Chloride (Cl)	15	36
Total hardness as $CaCO_3$	62	69
Dissolved solids	180	214
Rw, ohms/m^2m at 25°C.	37.42	25.64

Porosity determination
(from electric log and water analysis)

$Rt = Rw/P^m$ (equation (1), p. 117)
Physical conditions for aquifer, *in situ:*
(1) Convert Rw of formation water at standard temperature to Rw of water *in situ* (23.33°C.) 25.64 (from lab. analysis/0.96 (from corr. chart, fig. 10) = 26.71 ohms/$m^2m = Rw$
(2) $Rt = 131$ ohms/m^2m
(3) Cementation factor m, average for sands and gravels of the Prairie formation of Pleistocene age (p. 12) = 1.65
Then $131 = 26.71/P^{1.65}$, or $P^{1.65} = 26.71/131 = 0.2039$
$P = \sqrt[1.65]{0.2039}$; $\log P = \log 0.2039/1.65 = 9.03094 - 10/1.65$
$= 5.4733 - 6.0606$
$= 9.4127 - 10$
P = antilog $9.4127 - 10 = 25.87\%$; laboratory value = 34.73

SUMMARY AND CONCLUSIONS

Electrical tests of formation samples obtained from granular aquifers by hydraulic-rotary drilling give resistivity data sufficiently accurate to enable calculation of the formation factor and cementation factor. Water quality in granular aquifers of great areal extent is sufficiently constant in its gradation in quality and electrical resistivity to enable preparation of a type curve for each aquifer or zone of aquifers. An approximate hypothetical analysis using this type curve can be derived from a single water-resistivity value, obtainable from the electric log and the formation-sample test.

Analytical study of the electrical technique, applied to ground water, has been possible on a regional basis for only a few years. Data that will make the technique increasingly useful are accumulating rapidly, and this report is intended not as a final pronouncement upon the utility of the method, but as a

spur to its application. Extensive laboratory study of formation samples, cuttings and cores, thorough statistical analysis of quality-of-water records, and preparation of detailed maps showing textural changes, structural conditions, and directions and rates of ground-water flow are only a few of the projects that must be accomplished before the electrical technique can be perfected and applied with confidence by the ground-water hydrologist.

BIBLIOGRAPHY

Archie, G. E., "The Electrical Resistivity Log as an Aid in Determining Some Reservoir Characteristics," *Amer. Inst. Min. Met. Eng., Tech. Pub. 1422, Petroleum Technology* (January 1942) 8 pages.

Doll, H. G., *Resistivity Departure Curves*, Schlumberger Well Surveying Corp. (September 1947) 31 pages.

Graton, L. C., and Fraser, H. J., "Systematic Packing of Spheres"; "Experimental Study of Porosity and Permeability of Clastic Sediments," *Jour. Geology*, 43, no. 8 (November-December 1935) 806–807.

Guyod, Hubert, "Electrical Well Logging, 13, Electrical Properties of Oil-Bearing Reservoirs," *Oil Weekly* 115, no. 11 (November 1944) 81–82.

———"Electrical Log Interpretation, 3, True Resistivity," *Oil Weekly*, 120, no. 3 (December 17, 1945) 15–20.

——— "Electrical Logging Developments in the U.S.S.R.; 1, Resistivity of Non-Invaded Formations, and 2, Resistivity of Mud-Invaded Formations," *World Oil*, 127, nos. 7 and 8 (December 1947–January 1948) 4–12.

Jones, Park J., "Application of Electric Logs," *Petroleum Production*, Vol. 1, (1946)

Slichter, C. S., "Theoretical Investigation of the Motion of Ground Water," *U. S. Geological Survey 19th Annual Report*, Part 2 (1899) pp. 305–328.

INDEX OF WELLS SHOT FOR VELOCITY*

(Third Supplement)

B. G. SWAN†

ABSTRACT

Information is listed on 498 well velocity surveys not previously reported in the three earlier publishings of the Index. Most of these are new surveys shot since the fall of 1948. Corrections and additional information on surveys previously listed are also given.

INTRODUCTION

This is the third supplement to the original "Index of Wells Shot For Velocity," published in the October 1944 issue of *Geophysics*. Its publication is of course possible only through the cooperation of the geophysical industry as a whole, and the Editors of *Geophysics* wish to thank those individuals and companies for the time and effort expended in supplying the writer with the requested data.

The first portion of this supplement shows surveys not previously reported in any of the previous editions. Most of these are surveys shot since the fall of 1948. In the latter portion, corrections and additional information on previously listed surveys are shown in italics. In all, 498 new surveys are listed. One new abbreviation appears in the "Shot by" column. "DEC" denotes Delta Exploration Company.

It should be noted that the heading for the "Depth" column has been changed to "Survey Depth." This has been done to clarify the intended meaning of this column. The figures shown are supposed to indicate the maximum depth of usable information obtained in the velocity survey.

The writer is grateful to Mrs. Evelyn Ledeker, who did all the detail work necessary in the preparation of this supplement.

* Manuscript received by the Editor October 12, 1950

† Continental Oil Co., Ponca City, Oklahoma, serving as special editor to compile and revise this index.

INDEX OF WELLS SHOT FOR VELOCITY

(Third Supplement)

STATE OF ALABAMA

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Houston	Union Prod.	No. 1 Kirkland	20, 7N-11W	8,100	Gulf	1949	Gulf
Washington	Humble	No. 2 Williams	C SE NW 21, 6N-4W	15,050	Atlantic	1949	Atlantic-Shell

STATE OF ARKANSAS

Union	C. H. Murphy & Co.	No. 1 Gregory	28, 19S-18W	9,499	Petty	1950	Murphy & Co.
Union	Richardson	No. 1 Shell-Pratt	36, 19S-15W	9,060	Shell	1948	Shell
Union	Carter	No. 1 Russell	C SW NW 33, 17S-16W	8,376	Carter	1949	Carter
Union	Carter	No. 1 Reynolds-Gammil Lbr. Co.	C SE NW 10, 18S-17W	7,896	Carter	1949	Carter

STATE OF CALIFORNIA

Colusa	Standard	No. 1 Elsey Est.	31, 14N-1W	3,500	GSI	1949	CWVSG
Kern	Texas Co.	No. 2-1 Voight	32, 27S-20E	5,500	Texas Co.	1948	CWVSG
Kern	Ohio	No. 1 Mitchell Ranch	3, 32S-29E	12,705	GSI	1948	CWVSG
Kern	Standard	No. 27-6 KCL	5, 28S-23E	13,200	GSI	1949	CWVSG
Kern	T & M Co.	No. 1 Shearer	26, 29S-22E	7,700	GSI	1949	CWVSG
Kern	Standard	No. 4-65 Tejon Ranch	8, 11N-18W	2,585	GSI	1950	CWVSG
Kings	Standard	No. 1 Hughes	30, 23S-22E	2,700	GSI	1948	CWVSG
Kings	Getty	No. 1 Orangeville Comm.	27, 18S-20E	8,810	Shell	1948	CWVSG
Kings	Shell	No. 1 Hacienda	12, 24S-20E	4,994	Shell	1948	CWVSG
Monterey	Barnsdall	No. 1 P. W. & P.	29, 23S-11E	4,143	WGC	1948	CWVSG
Monterey	Texas Co.	No. 1 Cooper	19, 21S-9E	3,074	Texas Co.	1946	CWVSG
Monterey	Texas Co.	No. 1 Currell	4, 21S-8E	3,250	Texas Co.	1946	CWVSG
Orange	Tidewater	No. 1 Martin	21, 5S-10W	6,280	Amerada	1948	CWVSG
Orange	Amerada	No. 68-6 Lamb Comm.	6, 6S-10W	10,300	Amerada	1948	CWVSG
San Joaquin	Amerada	No. 25-2 Martenet	2, 2N-8E	3,237	UGC	1948	CWVSG
San Luis Obispo	General Pet.	No. 84-25 Clarke	25, 26S-14E	5,660	GSI	1950	CWVSG
San Luis Obispo	Continental	No. 1 LeRoy	2, 10N-36W	2,810	GSI	1948	CWVSG
San Luis Obispo	Continental	No. 5 LeRoy	2, 10N-36W	3,012	GSI	1949	CWVSG
Santa Barbara	Richfield	No. A-73-16 Russell	16, 10N-27W	4,700	WGC	1948	CWVSG
Santa Barbara	Ohio & Indep. Explor.	No. 1 Kirschenmann	12, 10N-27W	7,050	WGC	1948	CWVSG
Santa Barbara	Richfield	No. A-1 Reyes	9, 9N-25W	6,010	GSI	1949	CWVSG
Ventura	Standard	No. 1 Maxwell	23, 2N-23W	11,600	WGC	1948	CWVSG
Ventura	Standard	No. 2-1 Fillmore Comm.	24, 4N-20W	10,500	GSI	1944	CWVSG
Ventura	Superior	No. 1 Saticoy	10, 2N-22W	12,030	GEC	1947	CWVSG
Yolo	Shell	No. 2-1 Pleasant Creek Unit	17, 8N-1W	4,493	Shell	1948	CWVSG

STATE OF COLORADO

Bent	Shell	No. 1 Colorado State	NW NE NE 3, 21S-50W	6,175	Shell	1950	Shell
Crowley	J. B. Stoddard & Colo. Fuel & Iron	No. 1 Wright	C SE NE 11, 20S-58W	7,000	Gulf	1949	Colo. F & I
Crowley	Gulf	Tepee Buttes	C SE SE NW 36, 18S-56W	7,176	Gulf	1949	Gulf
Logan	Plains Expl.	No. 1 Gillham	NW SE 23, 11N-52W	4,902	SSC	1949	RMSWSA
Logan	Carey-Plains-Republic	No. 1 Conklin	C NW SW 23, 10N-51W	4,443	SSC	1950	Plains Explor.
Morgan	Murphy & Carey Drlg.	No. 1 Mowery	C S/2 NW SE 6, 2N-56W	5,994	Shell	1949	RMSWSA
Weld	Shell	No.1 Hanson	NE NE NE 33, 8N-59W	7,242	Shell	1950	Shell

STATE OF INDIANA

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Clay	Carter	Strat. Test	SW SW SW 6, 13N-6W	1,240	Carter	1950	Carter
Clay	Carter	Strat. Test	NW NW SE 10, 13N-7W	1,304	Carter	1950	Carter
Parke	Carter	Strat. Test	SE SE NE 12, 15N-7W	1,135	Carter	1950	Carter
Parke	Carter	Strat. Test	SW SW SW 34, 16N-8W	1,231	Carter	1950	Carter
Parke	Carter	Strat. Test	NE NW NW 34, 14N-7W	1,253	Carter	1950	Carter
Sullivan	Carter	No. 1 Tressa Mae Patton	SW SE NW 7, 8N-10W	3,247	Oil Explor.	1950	Carter
Vigo	Carter	No. 1 Pigg	NW SE SW 30, 13N-7W	1,840	Carter	1950	Carter
Vigo	Carter	Strat. Test	SW SW NE 32, 13N-7W	1,455	Carter	1950	Carter

STATE OF KANSAS

Barber	Lindas & Armer, et al.	No. 1 Pfaff	NW SE NE 15, 34S-10W	5,301	KVI	1948	Atlantic
Finney	Shell	No. 1 Case	NE SE NW 7, 21S-30W	5,530	SGC	1950	Shell
Graham	Shell	No. 8 Knipp	SE SW 14, 9S-21W	3,835	Shell	1948	Shell
Hamilton	Shell	No. 1 Scott	SW NE SE 28, 22S-43W	5,525	KVI	1948	KVI
Hodgeman	Shell	No. 1 Springer	SE SW SW 24, 22S-24W	5,100	SGC	1950	Shell
Nemahh	Carter	No. 1 Gillbert Ld. Bank	NW NW SE 14,2S-14E	3,228	Carter	1949	Carter
Sheridan	Continental	No. 1 Pope	SW SW SE 18, 7S-29W	4,779	SSC	1950	Conoco
Sumner	Carter	No. 1 Weber	C NW SE 26, 31S-4W	4,617	Carter	1945	Carter
Sumner	Texas Co.	No. 1 Hobbisiefkin	3, 35S-3W		Texaco	1950	Texaco
Wabaunsee	Carter	No. 1 Dorgan	SW SW NE 6, 15S-10E	3,307	SSC	1949	Carter

STATE OF LOUISIANA

Bienville	Barnsdall et al.	No. 1 Davis Bros. Lbr. Co.	SW SE SE 7, 16N-4W	10,230	NGC	1948	SSWSA
Bossier	Union Prod.	Sec. #1, 13 Unit	13, 17N-11W	11,290	Union		Union Prod.
Caddo	Bert Fields-Texaco	No. 1 Thigpen-Herold	23, 16N-16W	9,002	Texaco	1950	Texaco
Caldwell	Sohio	No. B-1 LaSalle	33, 14N-5E	5,705	Sohio	1949	Sohio
Claiborne	Hunt	No. 1 Goodwin	21, 23N-7W	10,263	NGC	1948	Hunt
Claiborne	Ohio-Gulf	No. 1 Martin	3, 22N-7W	11,750	Gulf	1949	Gulf-Ohio
E. Baton Rouge	Union Prod. et al.	No. 1 East	52, 4S-1W	11,175	SEI	1946	Union
Jeff. Davis	Continental	No. 1 Fontenot	35, 9S-5W	12,005	WGC	1950	Calif. Co.
Plaquemines	Shell	No. 1 State Lse. 1270	Blk. 49, Main Pass Area Gulf of Mexico	11,800	Shell	1948	Shell
Plaquemines	Shell	No. 1 State Lse. 1008	Blk. 24, S. Pass (E. Bay) Area Gulf of Mexico	10,940	Shell	1950	Shell
Plaquemines	Calif. Co.	No. 1 La. State Lse. 822	Blk. 34, W. Delta Area Gulf of Mexico	13,920	Delta	1949	Calif. Co.
St. Bernard	Shell	No. 1 State Lse. 1280	Blk. 1, Chandeleur Sound Area Gulf of Mexico	10,210	Shell	1949	Shell
Union	Shell	No. 1 Frost	15, 22N-1E	8,825	Shell	1948	Shell
Union	Carter	No. 1 Hicks	C SE NW 22, 21N-3W	8,486	Carter	1949	Carter
Winn	Continental	No. 1 Mansfield Hardwood Lbr. Co.	34, 13N-4W	10,370	Conoco	1949	Conoco

STATE OF MISSISSIPPI

Franklin	Honolulu	No. 1 Shell	SE NE 26, 5N-2E	11,140	GGC	1949	SSWSA
Franklin	Hunt	No. 1 Graves	NW SE NW 29, 6N-2E	10,600	GGC	1949	Sinclair
Franklin	Barnsdall	No. 1 Wilkinson	19, 5N-4E	11,377	Atlantic	1948	Atlantic
Jefferson	Danciger	No. 1 Logan	18, 10N-1W	9,456	WGC	1949	SSWSA
Lamar	Honolulu	No. 1 Newman	22, 3N-16W	9,712	DEC	1949	Honolulu
Lamar	Union Prod.	No. 1 Bradshaw	19, 3N-16W	10,655	SEI	1948	Unilon
Lincoln	California	No. 1 McCarty	NE NW 19, 8N-9E	10,700	GGC	1949	Sinclair
Lincoln	Vaughey & Big Chief	No. 1 Burkett	14, 5N-7E	10,790	Atlantic	1948	Atlantic
Pike	Sells Pet.	No. 1 Board of Supervisors	C SW NW 16, 3N-9E	11,025	Atlantic	1949	Atlantic
Rankin	Lack & Nelson	No. 1 Ridgeway	C SE SE 35, 3N-2E	9,172	Shell	1947	Shell
Simpson	Union Prod.	No. 1 Gaylord	24, 2N-1E	9,594	SEI	1948	Union
Smith	Gulf	No. 1 King	NE SW 8, 10N-13W	8,290	Gulf	1945	Gulf
Yazoo	Carter	No. 1 Wilson	C SE SW 30, 12N-3E	12,221	Carter	1950	Carter

Smith	Gulf	No. 1 King	NE SW 8, 10N-13W	8,290	Gulf	1945	Gulf
Yazoo	Carter	No. 1 Wilson	C SE SW 30, 12N-3E	12,221	Carter	1950	Carter

STATE OF MONTANA

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Big Horn	Shell	No. 1 Crow (Ash Creek)	36, 9S-37E	10,000	UGC	1949	RMSWSA
Garfield	General Pet.	No. 5-25-P Freedom Dome	25, 16N-38E	9,015	WGC	1949	RMSWSA
Musselshell	Texas Pacific	No. 1 Unit B Northern Pacific	SE NW NE 11, 7N-27E	9,039	Petty	1950	RMSWSA
Musselshell	Texas Co.	No. 1 Hornung	2, 11N-29E	4,870	Texaco	1948	Texaco
Musselshell	Texas Co.	No. 1 N. P. "C"	13, 11N-27E	6,300	Texaco	1948	Texaco
Teton	General Pet.	No. 1 Black Leaf	14, 26N-9W	7,500	WGC	1948	Gen. Pet.

STATE OF NEBRASKA

Chase	Skelly	No. 1 Kilpatrick "A"	15, 8N-39W	5,303	SSC	1950	Skelly
Cheyenne	Ohio	No. 1 Knieval	2, 15N-49W	5,019	GGC	1949	RMSWSA
Garden	Stanolind	No. 1 Eldred	NE NE NW 32, 20N-45W	3,810	Stanolind	1950	RMSWSA
Morril	British American	No. 1 Worth	NW NW NW 9, 17N-51W	5,505	SSC	1950	RMSWSA
Perkins	Arnold	No. 1 Hutsell	SE SE NE 3, 9N-40W	3,556	Shell	1950	Shell

STATE OF NEW MEXICO

Chaves	Apache-Olson Drlg.	No. 1 Noble Trust	NE SW 18, 4S-27E	8,034	SEI	1950	Tide Water
Chaves	Barnsdall	No. 1 State A	23, 8S-32E	12,005	Magnolia	1949	Magnolia
Chaves	Humble	No. 1 Federal-Gorman	C NE NE 30, 15S-22E	5,835	Magnolia	1948	Magnolia
Chaves	Richfield	No. 3-1 White	6, 12S-29E	9,050	Magnolia	1947	Magnolia
Chaves	Richfield	No. 1 Mullis	21, 15S-29E	12,002	Magnolia	1947	Magnolia
Chaves	Richfield	No. 1 Trigg	35, 14S-27E	9,970	Magnolia	1948	Magnolia
Chaves	Magnolia	No. 1 Lightcap	SE SE 6, 8S-30E	7,950	Magnolia	1950	Magnolia
Chaves	DeKalb	No. 1 Lewis	13, 10S-26E	5,641	WGC	1946	Honolulu-Union
Chaves	Honolulu	No. 1 State	C NW SE 13, 11S-27E	6,925	Magnolia	1950	Magnolia
Eddy	Humble	No. 1 Federal Hobbs	24, 20S-24E	11,567	Humble	1950	SSWSA
Eddy	So. Union Prod.	No. 1 Elliott Federal	24, 18S-23E	9,805	Magnolia	1948	Magnolia
Eddy	Magnolia	No. 1 State "W"	16, 21S-22E	11,135	Magnolia	1948	Magnolia
Eddy	Humble	No. 1 Federal Wiggs	31, 24S-27E	14,865		1950	Humble
Lea	Phillips	No. 1 Shipp	20, 18S-37E	12,518	Shell	1949	Shell
Lea	Shell	No. 1 Carter	32, 17S-39E	13,930	Shell	1950	Shell
Lea	Humble	No. 1 State "X"	C NW NE 31, 11S-35E	13,138	SEI	1949	SSWSA
Lea	Gulf	No. 1 Saunders	C SE SW 34, 14S-33E	13,220	Gulf	1950	Gulf
Lea	Gulf	No. 1 Chamberlain	C NW NE 14, 15S-37E	11,497	Gulf	1950	Gulf
Lea	Amerada	No. 1 Hamilton	NE SW 35, 16S-38E	12,509	KVI	1949	Amerada
Lea	Amerada	No. 1 BTA State	C NW SE 2, 12S-33E	11,180	KVI	1949	Amerada
Lea	Texas Co.	No. 1 Ertel	27, 16S-38E	13,285	Texaco	1950	Texaco
Rio Arriba	Stanolind	No. 1 Rosa Unit	11, 31N-6W	7,800	Geotech	1949	Stanolind
Rio Arriba	Delhi	No. 1 Ingerwersen	C SE SE 20, 24N-2W	7,755	Century	1949	Conoco
Roosevelt	Shell	No. 1 Saunders	5, 8S-37E	8,650	Carr	1948	Shell
Roosevelt	Magnolia	No. 1 Smith	C SW SW 11, 7S-33E	9,980	Magnolia	1948	Magnolia
San Juan	Stanolind	No. 4 Ute Indians	35, 32N-14W	8,602	Garrett Expl.	1948	Stanolind

STATE OF NORTH DAKOTA

Burleigh	Conoco-Pure	No. 1 Davidson	SW SW SW 6, 140N-77W	6,950	Conoco	1949	Conoco-Pure
Mercer	Plymouth	No. 1 Leutz	C NW NE 28, 142N-89W	12,398	Shell	1950	Shell
Ward	Price Drlg.	No. 1 Kline	SE SE SE 16, 157N-85W	6,506	Petty	1949	OKWSA

STATE OF OKLAHOMA

Alfalfa	Texas Co.	No. 1 Maxwell	NE NW NE 18, 28N-12W	6,048	Texaco	1948	OKWSA
Beckham	Shell	No. A-1 Soelle	C NE SW 10, 10N-21W	9,890	Century	1950	Shell
Beckham	Shell	No. 1 Waters	NE SW 14, 10N-21W	9,100	Shell	1947	Shell

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Beckham	Decem Drlg.	No. 1 Hill	SE SW 11, 9N-21W	12,090	Shell	1950	Shell
Beckham	Shell	No. C-3 Walter	NE SE 23, 10N-21W	9,350	Shell	1950	Shell
Beckham	Shell	No. C-1 Kelly	SE SW 5, 10N-21W	10,123	Century	1950	Shell
Beckham	Shell-Conoco	No. B-1 Reynolds	SW SE 13, 10N-21W	9,933	Century	1950	Shell
Blaine	Superior	No. 1 Norris	17, 19N-10W	11,000	Superior	1945	Superior
Caddo	Superior	No. 51-11 Weller	11, 8N-12W	15,000	Superior	1946	Superior
Caddo	Texas Co.	No. 1 Yates	31, 5N-10W	13,600	Texaco	1948	Texaco
Canadian	Cities Service	No. 1 Petree	C SE SE 18, 11N-8W	11,100	SSC	1949	Cities Serv.
Carter	Shell	No. 1 Bristow	C SW SE 20, 3S-3W	11,945	Shell	1949	OKWSA
Garfield	Sun	No. 1 Thompson	SW SW SW 1, 24N-5W	6,104	SSC	1950	SSC
Harmon	California	No. 1 Wade	C SW NW 23, 1N-25W	9,091	SSC	1949	California
Jefferson	Amerada	No. 5 Edwards	4, 4S-4W	2,693	GRC	1949	Amerada
Jefferson	California	No. 1 Seay	22, 7S-5W	2,701	GSI	1949	California
Kay	Atlantic	No. 1 Hammon	NW NE SW 27, 29N-3E	3,752	KVI	1948	KVI
Kay	Carter	No. 1 Kildare Sch. Lds.	SE SE SE 13, 27N-1E	4,081	Rogers-Ray	1948	Carter
Kingfisher	Superior	No. 88-16 Long	SE SE SE 16, 17N-7W	9,015	Superior	1948	Superior
Kiowa	Stanolind	No. 1 Chappelear	SW SW NE 8, 7N-15W	3,500	KVI	1948	Amerada
Lincoln	Kingwood	No. 1 Betow	SW SW NW 10, 15N-3E	5,126	KVI	1948	Kingwood
Lincoln	Atlantic	No. 1 Shaw	SE NW NE 7, 13N-2E	5,633	KVI	1948	Atlantic
Love	Conoco-Texas Pacific	No. 1 Forbes	C NE NE NW 23, 6S-1E	5,476	Conoco	1950	Conoco
Love	California	No. 1 Brannan	30, 7S-3W	9,389	GSI	1949	California
Major	Superior	No. 1 Manning	27, 22N-10W	8,100	Superior	1945	Superior
Major	Wilcox	No. 1 Coulter	C SW NW 15, 22N-9W	7,890	Superior	1946	Superior
McClain	Cities Service	No. 1-B Lawson	C NE SW 22, 5N-4W	12,360	KVI	1946	Cities Service
McClain	Danciger	No. 1 Vandervort	NW NE NW 2, 7N-3W	9,427	SSC	1949	Danciger
McClain	Shell	No. 1 Kniffin	C SW NE 17, 5N-1E	6,212	Shell	1946	Shell
Noble	Callery & Hurt	No. 1 Wiegel	28, 20N-1E	5,400	KVI	1948	
Noble	Ashland	No. 1 Ponca Tribe	NW SW SE 1, 24N-1E	4,686	SSC	1949	Ashland
Okmulgee	Manhart	No. 1 Parks	NE NW NE 24, 13N-11E	3,165	SSC	1949	SSC
Payne	Turk	No. 1 Finnell	W/2 SW SW 5, 19N-1W	5,046	Std. Seis	1949	Std. Seis
Stephens	Vickers	No. 1 Walker-Voorheese	2, 2N-4W		Vickers	1947	Vickers
Washita	Texas Co.	No. 1 Wolfe	NW SW SW 20, 9N-20W	6,852	Shell	1945	Shell
Woods	Atlantic	No. 1 Murray	C NW SW 24, 26N-15W	7,264	KVI	1948	KVI
			STATE OF TEXAS				
District: East							
Anderson	Delta Drilling	No. 1 Russel	I&GN Survey, A-418	10,200	Petty	1950	Shell
Bowie	Gulf	No. 1 Veach	Jacob McFarland, A-384	10,167	GGC	1949	Shell
Freestone	Humble	No. 1 McWatters	Geo. Lamb Sur., A-402	16,000	Humble	1948	SSWSA
Freestone	Humble-Shell	No. 1 P.D.C. Ball Est.	J. Y. Aguilera Sur.	8,350	Petty	1950	Shell
Nacogdoches	Humble	No. 1 Crawford	Zimri Bennett Sur., A-9	8,150	Humble	1949	Humble
Rusk	Texas Co.	No. 1 Clarke	Wm. Howeth Sur., A-380	7,725	Texaco	1950	Texaco
Smith	Magnolia	No. 1 Fair	Wm. Schofield Sur., A-915	10,489	Magnolia	1948	Magnolia
Upshur	Tide Water	No. 1 Wade	J. H. Field Sur.	12,506	Shell	1950	Shell
District: Gulf Coast & South							
Aransas	Union Prod.	No. 1 Tatton	John Durst Survey	10,500	Petty	1950	Union
Aransas	Western Nat. Gas	No. 11 St. Charles Ranch	Aransas CSL, A-230	8,500	Petty	1949	Shell
Brazoria	Gulf	No. 2 Perry	S. F. Austin Sur., A-20	11,080	Petty	1949	Shell
Brazoria	J. S. Abercrombie Co.	No. 20 BRLD	Chas. Breen League	15,050	Petty	1950	Shell
Calhoun	Alcoa Mining & So. Prod.	No. D-1 Melbourn	Blk. 3, Benito M. Grant Sur.	9,560	Alcoa	1950	
Cameron	Texas Co.	No. 1 Water Control & Improv. Dist. #5	Blk. 402, El Jardin Subd.	12,000	IXC	1948	Texaco

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Cameron	Danciger-Singleton	No. 1 Weikel	Espiritu Santo Grant Sur.	9,975	Reliable	1950	Danciger
Chambers	Sun	No. 1 Brandt	Henry Baker Survey	12,165	Petty	1950	Shell
DeWitt	Western Nat. Gas	No. 1 Zingerle	James Quinn Sur., A-395	8,165	Petty	1948	Atlantic
Duval	Atlantic	No. B-1 Hagist Ranch	E. F. Cuellar Sur. #4, A-1902	9,175	Petty	1949	Shell
Duval	Argo	No. 1 McDowell	Copita F&G Ynojosa Grant	6,490	Petty	1949	Shell
Gonzales	Prod. Corp. of Nevada	No. 1 Austin	John A. Winn Sur., A-465	6,235	Petty	1950	Shell
Hardin	Gen. Crude & Sohio	No. 1 Taylor	B. Hughes Sur., A-277	8,650	Shell	1950	Shell
Harris	Gulf	No. 1 Ward	Wm. J. Lovett Sur., A-526	11,068	Gulf	1949	Gulf
Hidalgo	Continental	No. 1 Talbot	W. Sharyland Subd. Pro. 57	11,000	Petty	1949	SSWSA
Jim Hogg	Humble	No. 1 Izaguirre	Agua Nueva de Abajo Grnt.	7,477	Petty	1950	Shell
Kenedy	Sun	No. 1 State-Laguna Madre	Tract 228, in Laguna Madre	10,500	Sun	1949	Sun
Kenedy	Humble	No. D-1 Kenedy	San Pedro de Las Motas Gr.	11,987	Humble	1949	Humble
Kenedy	Humble	No. 1 Pasture	San Salvador del Tule, A-1	11,696	Humble	1950	SSWSA
Kenedy	Humble	No. C-2 Kenedy	Las Barrosas Gr., A-43	11,548	Humble	1950	SSWSA
Kenedy	Atlantic	No. 2 McGill	S. M. Boyd Sur. #78, A-5	9,985	Petty	1948	Atlantic
Kleberg	Humble	No. 1 Pasture	R.G.N.G. Sur. 307, A-64	11,855	Humble	1949	SSWSA
La Salle	Texas Co.	No. 1 La Salle	Peter McGreal Sur., A-582	9,200	Texaco	1948	SSWSA
La Salle	Plymouth	No. 1 Archbishop of San Antonio	Sec. 164, H&GN RR	12,499	Petty	1949	SSWSA
La Salle	Coquat & Amerada	No. 1 St. Louis Union Trust	BS&F Sur. #39, A-100	6,500	Petty	1950	SSWSA
La Salle	Siznod et al.	No. 1 Girard	Robt. Crawford Sur., A-1133	6,500	Petty	1950	Shell
Lavaca	Shell	No. 1 Steinman-King	HT&B RR Sur., A-245	8,777	Petty	1950	Shell
Live Oak	Coquat & Stanolind	No. 1 Briam	Dennis McGowen Sur., A-29	8,520	Petty	1950	Shell
Madison	West Drilling Co.	No. 1 Mathis	Arter Crownover Sur., A-13	9,967	Petty	1950	Shell
Medina	Humble	No. 1 Wilson	A.B.&M. Survey, A-381	7,074	Humble	1949	Humble
Montgomery	Amerada	No. 1 Gode	M. B. Lawrence Sur., #310	13,386	KVI	1949	Amerada
Newton	Fullerton Oil Co.	No. 1 White & West	Robert Goodwin Sur., A-4	10,660	Petty	1950	Shell
Nueces	Humble	No. G-2 East Laureles	Tr. 123, Laureles Farm Tr.	9,972	Humble	1949	SSWSA
Nueces	Skelly	No. B-2 Bailey	Tr. 16, Agua Dulce Farm Tr.	6,504	Keystone Exp.	1949	Skelly
Refugio	Union Prod.	No. A-4 Lambert	Lambert & Allen Sur.	6,240	SEI	1938	Union
Starr	Continental	No. B-121 Slick	CCSD&RGNG Sur. #222	9,993	Petty	1950	Shell
Starr	Texas Co.	No. 7-A de Guerra	Por. 68, Diego Hinojosa	9,000	Texaco	1949	Texaco
Tyler	Housh Drilling Co.	No. 1 Reid et al.	BBB&C RR Co. Sur. A-113	7,800	Petty	1949	Shell
Waller	Texas Co.	No. 1 Rice Institute	John Stevens Survey	12,045	Roger-Ray	1949	Texaco
Waller	Halbouty-Chicago Corp.	No. 1 Hooks et al.	S. F. Austin A-7	8,410	GGC	1949	SSWSA
Webb	H. M. Amsler	No. 1 Bruni Est.	HE&WT RR Sur. 1571, A-1476	7,000	Petty	1949	SSWSA
Webb	Shell	No. 1 Duval Co. Ranch	Zapata Co. Sch. Ld., Sur. #4	8,100	Petty	1949	SSWSA
Willacy	Humble	No. 1 B-1 Nopal	San Juan de Carricitos Gr.	9,280	Humble	1948	SSWSA
Wilson	Hewitt & Dougherty	No. 1 Mansford	J. F. Rodrigues Sur., A-263	6,495	Petty	1950	Shell
Zapata	Am. Republic Corp. et al.	No. 1 Hayes Est.	Los Mogotes Grant	8,610	Petty	1949	Shell
Zavala	Rockhill et al.	No. 1 Holdsworth	L. L. Everett Sur., A-66	7,240	Petty	1950	SSWSA
District: North							
Clay	Superior	No. 1 Seigler	Texas E&L Co. A-572	6,232	Shell	1941	Shell
Comanche	McQueen & McCurdy	No. 1 Datton	Beatty, Seale & Forwood Sur.	3,625	Humble	1949	Humble
Comanche	Burdell	No. 1 Kirk	F. Stigell Survey	3,192	Humble	1950	Humble
Comanche	United No. & So. Dev.	No. 1 Aldridge	David Scott Survey	4,860	Humble	1950	Humble
Coryell	Amerada	No. 1 Perkins	Margildo Ramirez Sur.	2,310	GRC	1949	Amerada
Coryell	Amerada	No. 1 Tate	Walter Campbell Sur.	4,865	GRC	1949	Amerada
Eastland	R. W. Fair	No. 1 Kent	T. J. Fennell Sur., A-135	3,652	Texaco	1948	SSWS
Eastland	Bankline Oil Co.	No. 1 Briggs-Owen	Sec. 48, Blk. 4, H&TC RR Co.	3,910	NGC	1950	Bankline
Erath	Continental	No. 1 Wylie	Lingleville #126, Whittaker S.	6,030	Conoco	1948	Conoco
Foard	Texas Co.	No. 1 Margaret	Sec. 431, Blk. A, H&TC RR	7,050			Texaco

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Grayson	Texas Co.	No. 1 Marshall	A. Tuttle Sur., A-1193	7,759	Texaco	1949	SSWSA
Hamilton	Amerada	No. 1 Briscoe	George Hodge Survey	4,400	GRC	1949	Amerada
Haskell	Anderson-Prichard	No. 1 Russell	Abst. A-371, O. Smith Sur.	6,010	SGC	1950	Anderson-Prichard
Knox	Humble	No. 1 Voss	Sec. 17, D.&W. RR Co.	6,087	Humble	1949	Humble
Knox	Stanolind	No. 1 Baker	Sec. 51, Blk. 2, D&W RR	5,840	Stanolind	1949	Stanolind
Knox	Sinclair	No. 1 Beavers	Sec. 224, Blk. 44, H&TC	6,359	Petty	1950	Shell
Montague	D. H. Bolin	No. 1 Cato Heirs	F. Robertson Sur., A-620	3,200	SGC	1950	Std. of Tex.
Montague	Kingwood	No. 1 Yates	Blk. 3, Hunt Co. Sch. Ld.	8,175	SSC	1950	Kingwood
Montague	Texas Co.	No. 1 Boedecker	Sec. 2852, Texas Emigr.	7,163	Texaco	1950	Texaco
Stephens	Texas Pacific	Hill	Sec. 12, Blk. 2, SPRR	4,557	IXC	1948	Texas Pacific
Throckmorton	F. M. Manning, Inc.	No. 1 Graham-Magnolia	TE&L Co. Sur. 985	4,532	IXC	1950	Manning
Throckmorton	F. M. Manning, Inc.	No. 1-D Davis	Bradley-Garner Sur.	4,675	IXC	1950	Manning
Throckmorton	Woodley Pet.	No. 1 Bryson	Sec. 911, TE&L Co.	4,604	NGC	1949	Woodley
Throckmorton	Cities Service	No. 99-1 Swenson	Sec. 99, BBB&C RR	5,799	KVI	1949	Cities Service
Wilbarger	Wagoner	No. 1 TT	Sec. 12, Blk. 4, H&TC RR	4,828	KVI	1948	KVI
Wilbarger	Waggoner Est.	No. 1 YY	Sec. 21, Blk. 6, H&TC RR	4,951	SSC	1949	Expl. Serv. Co.
Young	Humble	No. B-1 Daws	Sec. 770, A-775	5,120	Humble	1948	SSWSA
District: Panhandle							
Deaf Smith	Honolulu	No. 1 Ponder	Sec. 74, Blk. 68, Rambo SCL	9,600	UGC	1949	Honolulu
Donley	Honolulu	No. 1 Ozier	Sec. 55, Blk. 6, GC&SF	5,857	UGC	1948	Honolulu
Hansford	Gulf	No. 1 Collard	Sec. 7, Blk. 3, SA&MG RR	8,640	Gulf	1949	Gulf
Hansford	Gulf	No. 1-C Gamertsfelder	Sec. 5, PSL Blk. 4	9,196	Geotech.	1949	Gulf
Lipscomb	Gulf	No. 1-A Porter	Sec. 413, H&TC RR, Blk. 43	13,375	Gulf	1949	Gulf
Ochiltree	Texas Co.	No. 1 McGarraugh	Sec. 151, Blk. 13, T&NO	9,835	Texaco	1950	Texaco
Ochiltree	Gulf	No. 1 Stump	Sec. 12, Blk. 4T, T&NO	10,600	Geotech.	1949	Gulf
Ochiltree	Gulf	No. 1-A Wamble	J. J. Ballentine Sur.	11,250	Gulf	1950	Gulf
Roberts	Sinclair	No. 1 Lips	Sec. 135, Blk. C, G. Munson	9,552	Petty	1949	Sinclair
Roberts	Phillips	No. 1 Carruth	Sec. 66, Blk. 2, I&GNRR	11,300	SSC	1948	Phillips
Sherman	Phillips	No. 1-A Kathryn	Sec. 8, Blk. 3B, GH&HRR	5,980	SSC	1949	Phillips
District: West							
Andrews	Superior	No. 2-C University	Sec. 7, Blk. 13	6,813	Superior	1944	Superior
Andrews	Gulf	No. 1-X University	Sec. 2, Univ. Blk. 5	5,740	Gulf	1948	Gulf
Andrews	Humble	No. 2 Means	Sec. 9, Blk. A-23, PSL	3,900	Humble	1935	Humble
Borden	Sinclair	No. 1 Williams	Sec. 45, Blk. 32, T6N, EL&RR	10,015	Petty	1949	Sinclair
Borden	Ryan, Hayes, Burke-Std.	No. 1 Miller	Sec. 418, Blk. 97, H&TC Sur.	8,532	WGC	1949	Std. of Tex.
Borden	Amerada	No. 1 Canning	Sec. 117, Blk. 25, H&TC Sur.	8,388	GRC	1949	Amerada
Borden	R. R. Rutherford	No. 1 Griffin	Sec. 57, Blk. 25, H&TC Sur.	8,505	WGC	1950	Std. of Tex.
Borden	Std. of Texas	No. 1-6 Griffin	Sec. 35, Blk. 25, H&TC Sur.	8,910	WGC	1950	Std. of Tex.
Borden	Penrose & Livermore	No. 1 Baird	Sec. 37, Blk. 30, T6N, Gibson	8,250	UGC	1950	Honolulu
Borden	Honolulu	No. 1 Good	Sec. 2, Blk. 32, T3N1, T&P	9,690	UGC	1950	Honolulu
Cochran	Superior	No. 1 Cameron	League 86, Labor 9	7,000	Superior	1947	Superior
Coke	So. Min.-Seaboard	No. 1 Greenland	Sec. 2, BS&F Sur.	6,152	UGC	1950	SSWSA
Coke	Amerada	No. 2 March Ranch	Sec. 37, Blk. 2, D&SE Sur.	7,300	GRC	1950	Amerada
Crane	Humble	No. 1 Cowden	Sec. 58, CCSD&RGNG Blk. X	11,000	Gulf	1949	Gulf
Crockett	Amerada	No. C-1 Shannon	Tr. 34, Lg. 2, Archer CSL	7,975	GRC	1948	Amerada
Crockett	Amerada	No. D-1 Shannon	Lot 2, Lg. 3, Archer CSL	6,950	GRC	1948	Amerada
Crockett	Humble	No. 1 Harvick	Sec. 80, Blk. GH, GC&SF	8,850	Humble	1948	Humble
Crockett	Shell	No. 1 Kincaid	Sec. 6, Blk. MN	8,370	Shell	1948	Shell
Crockett	Moore Esp.	No. 1 Shannon	Sec. 21, Blk. YZ, GC&SF	7,998	NGC	1949	Southland
Crosby	Gulf	No. 1 Martin	Sec. 3, Blk. 4, WTRR	8,420	Gulf	1950	Gulf
Culbertson	Gulf	No. 1-F Grisham-Hunter	Sec. 16, PSL Blk. 54	12,050	Gulf	1948	Gulf
Culbertson	Gulf	No. 1 Grisham	Sec. 18, Sch. Blk. 99	5,977	Gulf	1950	Gulf

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Dawson	Carraway	No. 1 Loe	Lbr. 12, Lg. 3, Taylor CSL	9,400	GSI	1949	Std. of Tex.
Dawson	Seaboard	No. 1 Barrow	Sec. B, Blk. 35, T6N, GRR	11,637	SEC	1949	SSWSA
Dickens	Union	No. 1 Elliot	Sec. 177, Blk. 1, H&GN RR	8,050	WGC	1949	Union
Ector	Stanolind	No. 2 Realty	Sec. 14, Blk. B-14, PSL	10,755	WGC	1950	Stanolind
Fisher	Horrigan & Fohns	No. 1 Jameson	Sec. 111, Blk. 1, H&TC RR	6,121	NGC	1950	Shell
Fisher	Std. of Texas	No. 1 Schubert	A-322, Blk. 1, J&L, Bastrop	6,199	GSI	1948	Std. of Tex.
Floyd	Livermore-Honolulu	No. 1 Krause	Sec. 29, Blk. K, T&T	7,738	UGC	1946	Honolulu
Gaines	Union-Honolulu	No. 2-B Doss	Sec. 360, Blk. G, CCSD&RGNG	10,872	UGC	1949	Honolulu
Gaines	Magnolia	No. 1 Hicks	Sec. 7, Blk. 4, Loving CSL	13,251	Magnolia	1949	Magnolia
Gaines	Forest & And.-Prichard	No. 1-A Parmer CSL	Lbr. 12, Lg. 317, Parmer CSL	13,970	SGC	1950	Forest
Garza	Seaboard-Republic	No. 1 Ranch	Sec. 2, Blk. 5, GHH Sur.	8,280	Rayflex	1949	Seaboard-Republic
Glasscock	Shell	No. 1 Neal	Sec. 38, Blk. 33, T3S, T&P	3,547	Shell	1939	Shell
Glasscock	Shell	No. 2 TXL	Sec. 23, Blk. 32, T4S, T&P	9,798	GGC	1950	Shell
Glasscock	Shell	No. 1 Clark	Sec. 5, Blk. 32, T4S, T&P	10,955	Stanolind	1946	SSWSA
Hockley	Humble	No. 1 Hobgood	Lbr. 10, Lg. 693, St. Cap. Ld.			1950	SSWSA
Hockley	Honolulu-Signal	No. 1-24 Ellwood	Lbr. 24, Lg. 5, Wilbarger CSL	11,600	UGC	1948	Honolulu
Hockley	Big Chief Drilling Co.	No. 1 DeLoache	Sec. 22, Lg. 77	11,420	Stanolind	1950	Stanolind
Howard	Shell	No. 1 O'Daniel	Sec. 2, Blk. 30, T1N, T&PRR	8,705	NGC	1950	Shell
Howard	Magnolia	No. 1-A Gartner	Sec. 67, Blk. 20, Lavaca Navg.	8,520	Magnolia	1949	Magnolia
Howard	Seaboard	No. 2 Campbell	Sec. 29, Blk. 32, T3N, T&PRR	10,150	SEC	1948	SSWSA
Howard	Forest & So. Minerals	No. 1 Guthrie	Sec. 26, Blk. 31, T1N, T&PRR	9,375	SGC	1950	Forest
Irion	Frankel Bros.	No. 2 Tankersley	Sec. 19, GC&SFRR	7,827	NGC	1949	Shell
Irion	Shell	No. 1 Owens-Univ.	Sec. 2, Univ. Blk. 43 Univ. Ld.	9,500	NGC	1949	Shell
Irion	Shell	No. 1 Town-Univ.	Sec. 3, Blk. 40, Univ. Lds.	9,800	NGC	1948	Shell
Kent	Barnsdall-Seaboard	No. 1 Spires	Sec. 22, Blk. 4, H&GNRR	7,539	Rayflex	1950	Barnsdall-Seaboard
Kent	Lohman et al.	No. 1 Young	Sec. 98, Blk. G, W&NWRR	7,885	Rayflex	1950	Seaboard-Lohman
Kent	Spartan et al.	No. 1 Wallace Est.	Sec. 97, Blk. G, W&NWRR	7,861	Rayflex	1950	Seaboard-Spartan
Kent	L. H. Wentz	No. 1 Fuqua	Sec. 7, Blk. B, PSL Sur.	6,970	Petty	1949	Wentz
Kent	Drilling & Explor.	No. 1 Connell	Sec. 19, Blk. 5, H&GN Sur.	7,925	UGC	1950	Honolulu
Lamb	Forest-Jergens	No. 1 Harris	Sec. 15, Blk. 661, CSL	7,220	UGC	1947	Honolulu
Lamb	Honolulu	No. 1 Halsell	Sec. 19, Blk. 219, Castro CSL	9,100	UGC	1947	Honolulu
Lamb	Seaboard	No. 1 Jackson	Sec. 15, Blk. 680, CSL	9,240	UGC	1947	Honolulu
Lubbock	Honolulu	No. 1 Rhodes	Sec. 8, Blk. E, G&SF	10,430	UGC	1947	Honolulu
Lynn	Snowden et al.	No. 1 Williams	Sec. 1407, Blk. 1, EL&RR	9,180	Rayflex	1950	Snowden et al.
Lynn	Honolulu	No. 1 King	Sec. 424, Blk. 21, HE&WT	10,735	UGC	1947	Honolulu
Lynn	Magnolia	No. 1 Garza Land & Cattle Co.	Sec. 431, Blk. 9, EL&RR	8,620	Magnolia	1950	SSWSA
Lynn	McAlester Fuel Co.	No. 1 Edwards	Sec. 58, GRR Survey	11,260	UGC	1949	Honolulu
Martin	Texas Co.	No. 1-X State	Sec. 17, Blk. 7, U. of Tex.	13,410	Texaco	1950	Texaco
Midland	Gulf	No. 1-E Bryant	Sec. 36, T&P, Blk. 39, T3S	13,750	Gulf	1948	Gulf
Midland	Texas Co.	No. 1 Scharbauer	Sec. 20, Blk. 40, T2S, T&P	13,061	Magnolia	1948	SSWSA
Midland	Harvey	No. 1 Floyd	Sec. 16, Blk. 37, T3S, T&P	12,050	Gulf	1948	Gulf
Mitchell	Hurlburt-Olson	No. 1 Elwood Est.	Sec. 17, J. P. Smith Sur.	7,622	Carr	1949	Humble
Mitchell	Std. of Texas	No. 1 Dunn	Sec. 64, Blk. 20, Lavaca Navg.	8,315	WGC	1949	Std. of Texas
Mitchell	Sun	No. 2 Ellwood Est.	Sec. 25, Blk. 16, SPRR Sur.	7,685	SEI	1948	Sun
Mitchell	Ohio	No. 1 Merket	Sec. 13, H&GN Blk. 3	7,690	GGC	1950	Ohio
Mitchell	J. W. Murchison	No. 1 Womack	Sec. 8, Blk. 26, HATC RR	8,121	SGC	1950	Std. of Texas
Nolan	Ohio	No. 1 City of Sweetwater	Sec. 43, T&P Blk. 22	7,115	GGC	1949	Ohio
Nolan	Sweetwater Expl. Co.	No. 1 Davis	Sec. 165, Blk. 1-A, H&TCRR	6,723	UGC	1949	Honolulu
Reagan	Superior-Atlantic	No. 1 Univ. Blk. 11-A	Sec. 20, Blk. 11 UTL	9,690	Atlantic	1949	SSWSA
Reagan	Atlantic	No. 1 Univ. 48-A	Sec. 18, Blk. 48 UTL	9,980	Atlantic	1949	Atlantic
Reagan	York & Harper	No. 1 Sugg	Sec. 104, Blk. 2, T&P	10,169	NGC	1949	SSWSA

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Reeves	Gulf	No. 1 Northrup	Blk. 50, Twp. 8 T&P	5,345	Gulf	1950	Gulf
Reeves	Gulf	No. 1-B Collier	Sec. 31, Blk. 51, Twp. 8, T&P	5,275	Gulf	1950	Gulf
Reeves	Gulf & Jack Frost	No. 1 Kinnear Est.	Sec. 23, Blk. 50, Twp. 8, T&P	5,440	Gulf	1950	Gulf
Reeves	Hill & Hill	No. 1 Texzona	Sec. 20, Sch. Blk. 57	3,950	Gulf	1950	Gulf
Runnels	Humble	No. D-1 Odem	J. Bird Survey (469)	5,280	Humble	1950	Humble
Schleicher	Honolulu	No. 1 Tisdale	Sec. 64, Blk. LL, GC&SF	6,940	UGC	1949	Honolulu
Schleicher	La Gloria Corp.	No. 1 Ewing	Sec. 15, Blk. M, GH&SA	6,828	Magnolia	1949	Magnolia
Scurry	Superior	No. 1 Jordan	Sec. 579, Blk. 97, H&TC	8,717	Superior	1949	Superior
Scurry	Superior	No. 10 Marley	Sec. 600, Blk. 97, H&TC	8,448	Superior	1950	Superior
Scurry	Humble	No. 1 Edmondson	Sec. 437, Blk. 97, H&TC	8,300	Humble	1949	Humble
Scurry	Magnolia	No. 1 Winston Bros.	Sec. 37, Blk. 1, Kirland & Fields	7,898	Magnolia	1948	Magnolia
Scurry	Lion	No. 17 McLaughlin	Sec. 197, Blk. 99, H&TC	6,615	Geotech.	1949	Lion
Scurry	Collins	No. 2 Parks	Sec. 442, Blk. 97, H&TC	7,450	WGC	1949	Std. of Texas
Scurry	Std. of Texas	No. 5 Lse. 2 Brown et al.	Sec. 440, Blk. 97, H&TC	8,143	WGC	1949	Std. of Texas
Scurry	Cities Service	No. 1 Burney	Sec. 143, Blk. 97, H&TC	8,225	GGC	1948	Cities Service
Scurry	Burdell	No. 1 Brown	Sec. 65, Blk. 3, H&GN	8,000	UGC	1950	Honolulu
Scurry	Spartan Drlg.	No. 1 Langford	Sec. 240, Blk. 97, H&TC	8,200	UGC	1950	Honolulu
Scurry	Texas Co.	No. 1 Fuller	Sec. 497, Blk. 97, H&TC	6,882	Texaco	1949	Texaco
Scurry	Std. of Texas	No. 2 West	Sec. 268, H&TC, Blk. 2	7,553	WGC	1950	Std. of Texas
Sterling	Amerada	No. E-1 TXL	Sec. 37, Blk. 32, T4S, T&P	9,660	GRC	1948	Amerada
Stonewall	Barnsdall	No. 1 Sloan-Callaway	Sec. 62, Blk. F, H&TC RR	6,330	UGC	1949	Honolulu
Stonewall	Paul Moss	No. 1 Smith Bros.	Sec. 127, H&TCRR, Blk. D	6,350	GGC	1948	Pan Am. Prod.
Stonewall	Delta Gulf Drlg.	No. 1 Sparks	Sec. 161, H&TCRR			1950	SSWSA
Swisher	Humble	No. 1 Nanny Est.	Sec. 9, Blk. OD, Denwoody Sur.	9,590	UGC	1949	SSWSA
Terry	Tide Water et al.	No. 1 Nystel	Sec. 9, Blk. C-38, PSL	11,640	Texaco	1950	Tide Water et al.
Tom Green	Dorrance	No. 1 Johnson	Sec. 99, WCRR Sur.	5,670	Shell	1950	Shell
Tom Green	Shell	No. 1 Johnson	Tr. 21, WCRR Sur.	5,369	Shell	1950	Shell
Tom Green	Shell	No. 2 Johnson	Sec. 335½ M. McMillan Sur.	4,935	Shell	1950	Shell
Tom Green	Sohio & Strake	No. 1 Haverland	J. T. Ridgeway Sur. No. 2	4,960	Shell	1950	SSWSA
Tom Green	M. E. Davis	No. 1 Jones Est.	Sec. 190, Dist. 11, SPRR	5,995	GSI	1949	SSWSA
Upton	Samedan	No. 1 Neal	Sec. 26, Blk. B, HE&WT	11,815	Rayflex	1950	Samedan
Upton	Republic Nat. Gas	No. 1-E Barnett "A"	Sec. 40, Blk. Y, TCRR	12,010	Atlantic	1948	Atlantic
Upton	Magnolia	No. 1-A TXL	Sec. 31, Blk. 40, T4S, TPRR	13,070	Magnolia	1949	Magnolia
Upton	Richardson & Bass	No. 1 Neal	Sec. 9, Blk. Y, GC&SF	12,463	NGC	1948	Pure
Upton	Sinclair-Magnolia	No. 1 Davis	Sec. 20, Blk. 41, T5S, T&P	13,369	Magnolia	1950	Magnolia
Upton	Wilshire	No. 1 McElroy	Sec. 148, Blk. E, CCSD&RGNG	13,960	Gulf	1948	Gulf
Ward	Gulf	No. 8-E Wristen Bros.	Sec. 2, H&TC Blk. 5	9,060	Gulf	1948	Gulf
Winkler	Gulf	No. 125-E Keystone	Sec. 29, PSL Blk. B-2	11,450	Gulf	1948	Gulf
Winkler	Gulf	No. 146-E Keystone	Sec. 24, Sch. Blk. A-57	11,865	Gulf	1949	Gulf
Yoakum	Texas Co.	No. 1 Miller	Sec. 198, Blk. D, Gibson	6,079	UGC	1943	Honolulu
Yoakum	Honolulu	No. 1-B Wright	Sec. 13, Blk. D, Gibson	5,409	Texaco	1941	Texaco
Yoakum	Honolulu	No. 1 Cobb	Sec. 381, Blk. D, Gibson	11,650	UGC	1950	Honolulu
			STATE OF SOUTH DAKOTA				
Butte	Wm. Seyler Co., Inc.	No. 1 Carl Anderson	Sec. 12, T8N, R5E	5,756	NGC	1949	RMSWSA
Butte	Texas Pacific	No. 1 Seyler Anderson	Sec. 12, T8N, R5E	5,700	NGC	1950	RMSWSA
			STATE OF UTAH				
Grand	Pacific Western	No. 1 Thompson	Sec. 33, T21S, R21E	9,410	WGC	1949	RMSWAS
Uinta	California Co.	No. 1 Gusher	Sec. 35, T5S, R19E	9,760	NGC	1950	Calif. Co.

STATE OF WYOMING

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Campbell	Texas Co.	No. 2 Adon Unit	Sec. 2, T52N, R72W	9,680			Texaco
Converse	Shell-Sprecher	No. 1 Lam	Sec. 15, T33N, R75W	7,090	Geotech	1950	RMSWSA
Converse	Phillips	No. 2 South Cole Creek	Sec. 17, T34N, R76W	10,207	Phillips	1949	Phillips
Fremont	Atlantic	No. 1 Tribal	Sec. 25, T1S, R4E	11,870	Mtn. Geop.	1949	RMSWSA
Goshen	General Pet.	No. 45-32-P Van Tassel	Sec. 32, T30N, R60W	7,000	WGC	1948	Gen. Pet.
Johnson	Continental	No. 1 Sussex Unit	Sec. 17, T42N, R78W	7,854	Conoco	1949	Conoco
Lincoln	Union	No. 1 Moxa Area Gov.	Sec. 30, T19N, R112W	12,243	WGC	1949	RMSWSA
Natrona	Pure	No. 3 West Poison Spider	Sec. 10, T33N, R84W	10,125	Geotech.	1949	RMSWSA
Park	Stanolind	No. 1 Christiansen	Sec. 8, T55N, R100W	12,360	WGC	1949	RMSWSA
Sheridan	Union	No. 1 Badger Creek Unit	Sec. 23, T 57 N, R82W	9,830	UGC	1947	RMSWSA
Sublett	Superior	No. 1 Pacific Creek Unit	Sec. 27, T27N, R103W	19,700	SSC	1949	Superior
Sublett	General Pet.	No. 81-7-G Tip Top	Sec. 7, T28N, R113W	10,550	WGC	1948	RMSWSA
Sublett	Superior	No. 1 Fear	Sec. 15, T29N, R113W	3,830			Superior
Sweetwater	Carter	No. 1 Great Divide	Sec. 13, T26N, R93W	7,480	Carter	1949	Carter
Uinta	Shell	No. 1 LeRoy	Sec. 32, T16N, R117W	6,170	Geotech.	1949	Shell
Washakie	General Pet.	No. 65-2-G North Sand Creek	Sec. 2, T46N, R91W	10,142	WGC	1948	RMSWSA

FOREIGN COUNTRIES

CANADA

Alberta	P.S. and P.	No. 1 Redwater	Lsd. 13, S. 36, T. 57, R. 22, W4M	3,226	CEC	1949	Amerada
Alberta	Imperial	No. 1 Tangent	Lsd. 13, S. 18, T. 80, R. 23, W5M	7,578	Carter	1950	Imperial
Alberta	Calif. Standard	No. 1 Lacombe Prov.	Lsd. 11, S. 10, T. 40, R. 27, W4M	8,005	GSI	1949	Calif. Standard
Alberta	Davies-Decalta	No. 2 Hondo	Lsd. 2, S. 23, T. 70, R. 1, W5M	3,990	Heiland	1949	Barnsdall
Alberta	Interleduc	No. 1 Deans	Lsd. 9, S. 11, T. 21, R. 4, W4M	5,500	GSI	1948	Socony-Vacuum
Alberta	Hudson's Bay	No. 1 Birch Lake	Lsd. 1, S. 24, T. 50, R. 11, W4M	3,536	GSI	1948	Hudson's Bay
Alberta	Calif. Standard	No. 1 Burdette Prov.	Lsd. 5, S. 22, T. 8, R. 11, W4M	4,313	Geotech.	1945	Calif. Standard
Alberta	Union	No. 1 Picardville	Lsd. 14, S. 36, T. 58, R. 27, W4M	5,002	United	1949	Union
Alberta	Bear	No. 1 Hollywood	Lsd. 4, S. 1, T. 67, R. 21, W4M	2,879	SSC	1949	Bear
Alberta	Gulf	No. 4 Aloisio	Lsd. 4, S. 5, T. 62, R. 24, W4M	2,122	Gulf	1950	Gulf
Alberta	Anglo-Canadian	No. 1 St. Ann	Lsd. 9, S. 28, T. 55, R. 4, W5M	5,985	Texaco	1948	Texaco
Alberta	Shell	No. 1 Runaway Lake	Lsd. 16, S. 25, T. 86, R. 20, W5M	6,075	Century	1950	Shell
Alberta	Gulf	No. 1 Upton	Lsd. 1, S. 11, T. 34, R. 21, W4M	6,601	Gulf	1949	Gulf
Alberta	Hudson's Bay	No. 1 Winnifred	Lsd. 11, S. 6, T. 12, R. 9, W4M	4,800	GSI	1949	Hudson's Bay
Alberta	Bear	No. 1 Villa	Lsd. 7, S. 8, T. 74, R. 14, W5M	6,350	SSC	1949	Bear
Alberta	Calif. Standard	No. 1 Brook Strathmore	Lsd. 7, S. 22, T. 30, R. 11, W4M	5,150	GSI	1949	Calif. Standard
Alberta	Bailey-Michel	No. 1 Castor	Lsd. 13, S. 4, T. 38, R. 14, W4M	4,698	GSI	1949	Calif. Standard
Alberta	Pan-Western	No. 1 West Edmonton	Lsd. 14, S. 21, T. 52, R. 25, W4M	5,602	GSI	1949	Calif. Standard
Alberta	Sun	No. 1 Langdon CPR	Lsd. 1, S. 3, T. 23, R. 27, W4M	6,448	GSI	1949	Sun
Alberta	Barnsdall	No. 1 Western Wabiskaw	Lsd. 11, S. 17, T. 78, R. 2, W5M	5,769	United	1950	Barnsdall
Alberta	Anglo-Canadian	No. 1 Tower-Killam	Lsd. 5, S. 18, T. 42, R. 13, W4M	3,431	Imperial	1948	Imperial
Alberta	Canadian Superior	No. 1–6 Ronald	Lsd. 1, S. 6, T. 38, R. 15, W4M	8,348	Can. Superior	1950	Can. Superior
Alberta	Canadian Superior	No. 15-28 Crown	Lsd. 15, S. 28, T. 36, R. 17, W4M	4,778	Can. Superior	1950	Can. Superior
Alberta	Canadian Superior	No. 15-20 Bird	Lsd. 15, S. 20, T. 37, R. 15, W4M	4,586	Can. Superior	1950	Can. Superior
Alberta	Canadian Superior	No. 13-10 Harrison	Lsd. 13, S. 10, T. 40, R. 18, W4M	5,391	Can. Superior	1950	Can. Superior
Alberta	Canadian Superior	No. 7-3 Mulligan	Lsd. 7, S. 3, T. 56, R. 24, W4M	3,891	Can. Superior	1950	Can. Superior
Alberta	Petromine	No. 1 Ribstone	Lsd. 8, S. 31, T. 43, R. 2, W4M	3,780	Nance Explor.	1949	Can. Superior
Alberta	Tower Petroleum	No. 1 Tower Stettler	Lsd. 13, S. 7, T. 37, R. 18, W4M	5,994	Can. Superior	1950	Can. Superior
Alberta	Western Prairie-Sacony	No. 1 Endiang	Lsd. 12, S. 16, T. 34, R. 15, W4M	4,980	Can. Superior	1949	Can. Superior
Alberta	Sun	No. 1 Coronation Province	Lsd. 12, S. 11, T. 37, R. 11, W4M	3,993	Sun	1949	Sun
Alberta	Continental	No. 1 Boyle	S. 22, T. 65, R. 19, W4M	4,000	SSC	1949	Bear
Alberta	Socony Vac.	No. 1 Craigmyle	Lsd. 12, S. 32, T. 32, R. 16, W4M	6,807	GSI	1949	Socony Vac.
Alberta	Socony Vac.	No. 1 Morrin	Lsd. 15, S. 9, T. 32, R. 19, W4M	6,439	GSI	1949	Socony Vac.
Alberta	Socony Vac.	No. 1 Verdant Valley	Lsd. 4, S. 14, T. 28, R. 18, W4M	5,552	GSI	1949	Socony Vac.
Alberta	Socony Vac.	No. 1 North Branch	Lsd. 13, S. 3, T. 2, R. 19, W4M	4,050	GSI	1949	Socony Vac.

County	*Company*	*Lease*	*Location*	*Survey Depth*	*Shot by*	*Date*	*Sponsored by*
Alberta	Socony Vac.	No. 1 Delia	Lsd. 10, S. 25, T. 32, R. 18, W4M	6,079	GSI	1950	Socony Vac.
Alberta	Socony Vac.	No. 1 Sunnybrook	Lsd. 15, S. 11, T. 49, R. 2, W5M	7,423	GSI	1950	Socony Vac.
Alberta	Socony Vac.	No. 1 Flint	Lsd. 13, S. 17, T. 45, R. 21, W4M	4,878	GSI	1950	Socony Vac.
Alberta	Socony Vac.	No. 1 Begreville	Lsd. 14, S. 20, T. 51, R. 15, W4M	3,870	NW Seis Sur.	1949	Socony Vac.
Alberta	N. F. A.	No. 1 Muskeg	S. 24, T. 57, R. 6, W6M	9,650	Imperial	1948	N. F. A.
Alberta	Imperial	No. 1 Clyde	Lsd. 9, S. 29, T. 59, R. 24, W4M	7,522	Imperial	1948	Imperial
Alberta	Consolidated	No. 2 Homestead	Lsd. 9, S. 31, T. 50, R. 25, W4M	5,752	Imperial	1948	Consolidated
Alberta	Gulf-Br. Dominion	No. 1 Radway	Lsd. 16, S. 26, T. 59, R. 21, W4M	3,620	Can. Gulf	1948	Can.-Gulf
Alberta	Texaco-McColl	Lisburn	Lsd. 1, S. 22, T. 56, R. 6, W5M	6,500	Texaco	1948	Texaco
Alberta	Imperial	No. 1 Dapp	Lsd. 5, S. 29, T. 62, R. 1, W5M	7,563	Imperial	1948	Imperial
Alberta	Amerada	No. 8-21-57-18 Crown	Lsd. 4, S. 21, T. 57, R. 18, W4M	3,281	Can. Explor.	1948	Amerada
Alberta	Gulf	No. 1 Onucki Can. Basin	Lsd. 7, S. 31, T. 61, R. 24, W4M	3,696	Gulf	1949	Gulf
Alberta	Picadilly Interleduc	No. 1 Edwards	S. 14, T. 38, R. 21, W4M	5,550	Gulf	1949	Gulf
Alberta	Pacific Sunray	No. 1 Halfway Lake	Lsd. 9, S. 19, T. 59, R. 23, W4M	4,432	Imperial	1949	Pacific Sunray?
Alberta	Clancey-Imperial	No. 1 Sylvan Glen	Lsd. 1, S. 18, T. 64, R. 26, W4M	4,225	Imperial	1949	Imperial
Alberta	Stanolind	No. 1 Decalta Perryvale	Lsd. 14, S. 11, T. 63, R. 23, W4M	3,920	WGC	1949	Stanolind
Alberta	Gulf	No. Marr	Lsd. 1, S. 29, T. 4, R. 29, W4M	12,600	Can. Gulf	1949	Can. Gulf
Alberta	Stanolind	No. 1 Plamondon	Lsd. 15, S. 9, T. 68, R. 16, W4M	2,500	WGC	1949	Stanolind
Alberta	Can. West.	No. 1 Pearson	Lsd. 14, S. 2, T. 38, R. 22, W4M	6,607	Can. Gulf	1949	Can. Gulf
Alberta	Stanolind	No. 1 Meadowbrook	Lsd. 5, S. 24, T. 63, R. 25, W4M	4,717	WGC	1949	Stanolind
Alberta	Canadian Gulf	No. 4 Bauer	Lsd. 4, S. 34, T. 37, R. 20, W4M	5,440	Can. Gulf	1949	Can. Gulf
Alberta	Stanolind-Imperial	No. 1 Barrhead	Lsd. 15, S. 10, T. 58, R. 5, W5M	6,414	Imperial	1949	Imperial-Stanolind
Alberta	Imperial	No. 1 Riverbend	Lsd. 4, S. 22, T. 54, R. 23, W4M	6,217	Imperial	1949	Imperial
Alberta	Midland Pet.-Imperial	No. 1 Midland Petroleums	Lsd. 11, S. 23, T. 52, R. 27, W4M	6,000	Imperial	1949	Midland Pet.-Imperial
Alberta	Imperial	No. 1 Bon Accord	Lsd. 1, S. 29, T. 56, R. 23, W4M	4,624	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Spirit River	Lsd. 12, S. 20, T. 78, R. 6, W6M	9,847	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Gibbons	Lsd. 2, S. 16, T. 56, R. 22, W4M	6,640	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Cones	Lsd. 16, S. 11, T. 61, R. 26, W4M	5,649	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Eldorena	Lsd. 4, S. 27, T. 57, R. 20, W4M	3,918	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Darling	Lsd. 16, S. 19, T. 62, R. 19, W4M	6,604	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Spruceheld	Lsd. 1, S. 31, T. 60, R. 19, W4M	3,561	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Clairmont	Lsd. 16, S. 25, T. 72, R. 5, W6M	11,710	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Figure Lake	Lsd. 11, S. 19, T. 62, R. 18, W4M	4,461	Imperial	1949	Imperial
Alberta	Imperial	No. 1 C. & S. Shaw	Lsd. 1, S. 20, T. 51, R. 22, W4M	5,368	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Normandville	Lsd. 1, S. 16, T. 79, R. 22, W5M	7,424	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Willingdon	Lsd. 14, S. 14, T. 55, R. 15, W4M	6,533	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Irma	Lsd. 6, S. 14, T. 46, R. 9, W4M	6,752	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Plain Lake	Lsd. 1, S. 11, T. 53, R. 12, W4M	6,433	Imperial	1949	Imperial
Alberta	Imperial	No. 1 Magloire	Lsd. 8, S. 17, T. 80, R. 21, W5M	7,770	Imperial	1950	Imperial
Alberta	Imperial	No. 2 Willingdon	Lsd. 11, S. 20, T. 55, R. 15, W4M	3,625	Imperial	1950	Imperial
Alberta	Imperial	No. 1 Pinedale	Lsd. 7, S. 28, T. 54, R. 16, W4M	4,591	Imperial	1950	Imperial
Alberta	Imperial	No. 6 Golden Spike	Lsd. 3, S. 22, T. 51, R. 27, W4M	6,454	Imperial	1950	Imperial
Alberta	Imperial	No. 1 Eyehill	Lsd. 13, S. 36, T. 35, R. 2, W4M	7,231	Imperial	1950	Imperial
Alberta	Imperial	No. 1 Kathleen	Lsd. 5, S. 1, T. 77, R. 20, W5M	7,837	Imperial	1950	Imperial
Alberta	Imperial	No. 253 Leduc	Lsd. 11, S. 13, T. 50, R. 27, W4M	7,494	Imperial	1950	Imperial
Alberta	Imperial	No. 1 Alpen	Lsd. 1, S. 28, T. 63, R. 20, W4M	4,151	Imperial	1950	Imperial
Alberta	Imperial	No. 1 Lalby	Lsd. 1, S. 12, T. 79, R. 22, W5M	7,847	Imperial	1950	Imperial
Alberta	Gulf	No. 1 Aloisio	Lsd. 4, S. 5, T. 62, R. 24, W4M	4,829	Gulf	1949	Gulf
Alberta	Casagama Oils	No. 1 Casagama	Lsd. 9, S. 7, T. 39, R. 19, W4M	5,500	WGC	1949	Casagama
Alberta	Barnsdall	No. 1 Wilson	Lsd. 14, S. 6, T. 17, R. 25, W4M	8,500	Century	1949	Barnsdall
Alberta	Sun et al.	No. 1 Calling Lake Proc.	Lsd. 13, S. 22, T. 71, R. 23, W4M	3,244	GSI	1950	Sun
Alberta	Gulf	No. 14 Brodie	Lsd. 14, S. 11, T. 40, R. 20, W4M	6,070	Can. Gulf	1950	Gulf
Alberta	Imperial	No. 1 Grosmont	Lsd. 13, S. 17, T. 67, R. 23, W4M	6,406	Heiland	1950	Imperial
Alberta	Gulf	No. 9 Mardell	S. 14, T. 34, R. 22, W4M	7,047	Can. Gulf	1950	Can. Gulf
Manitoba	Souris Valley Oil	No. 1 Moore	Lsd. 5, S. 20, T. 1, R. 27, P.M.	5,856	GSI	1949	Souris Valley Oil
Sackatchewan	Hudson's Bay	No. 1 Gronlid	Lsd. 15, S. 32, T. 47, R. 17, W2M	2,589	Atlantic	1950	Hudson's Bay

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Sackatchewan	Hudson's Bay	No. 1 Gronlid	Lsd. 15, S. 32, T. 47, R. 17, W2M	2,589	Atlantic	1956	Hudson's Bay
			BRAZIL, SOUTH AMERICA				
Bahia	Conselho Natl. Do Petr.	No. 60 Candeias	Coor. 1,746.85 M.S., 37.63 M.E.	1,200 m.	GSI	1949	Con. N. Do Pet.
			DENMARK				
	Danish American Prospecting Co.	No. 1 Øster Vraa	57°19.83′N of Equator 2°15.34′W of Copenhagen	1,700	Gulf	1949	DAPCO
	Danish American Prospecting Co.	No. 1 Ronnebjaerg	57°21.27′N of Equator 2°29.75′W of Copenhagen	2,450	Gulf	1949	DAPCO
			KUWAIT				
	Kuwait Oil Co.	No. 17	Coord. N-27,576 E-97,867	4,630	Seis. Ser. Ltd.	1948	Kuwait Oil Co.
	Kuwait Oil Co.	BG-62	Coord. N-36,586 E-99,318	4,810	Seis. Ser. Ltd.	1949	Kuwait Oil Co.
	Kuwait Oil Co.	Bg-57	Coord. N-29,051 E-106,569	4,700	Seis. Ser. Ltd.	1949	Kuwait Oil Co.
			MEXICO				
Vera Cruz	Petroleos Mexicanos	No. 1 Marcos	10 km. N of Martinez de la Torre	2,873 m.	GSI	1948	Pet. Mex.
Vera Cruz	Petroleos Mexicanos	No. 1 Santa Maria Ixcatepec	Corr. N 175, 350, E63,610	2,385 m.	GSI	1948	Pet. Mex.
			VENEZUELLA				
Anzoatequi	Mene Grande	ENS-112, District of Freites	N-182,610.20, E-565,146.60 Origin: Barcelona	8,500	Seisdel	1948	Mene Grande
Anzoatequi	Mene Grande	AM-8, District of Araqua	N-198,981.64, E-499,018.71 Origin: Barcelona	8,242	SSC	1948	Mene Grande
Anzoatequi	Mene Grande Creole	WGM-39, District of Freites	N-179,452.64, E-556,078.74 Origin:Barcelona	6,175	Seisdel	1948	Mene Grande
Anzoatequi	Mene Grande Creole	EGS-92, District of Freites	N-168,994.10, E-583,061.29 Origin: Barcelona	6,680	Seisdel	1948	Mene Grande
Anzoatequi	Socony-Vacuum	No. 5 Chimire, District of Freites	N-178,857.47, E-543,723.45 Origin: Barcelona	8,000	SSC	1948	Socony-Vacuum
Anzoatequi	Socony-Vacuum	NV-16, District of Freites	N-182,920.25, E-554,440.21 Origin: Barcelona	7,950	SSC	1948	Socony-Vacuum
Anzoatequi	V.O.+T (Shell)	VC-1, District of Bruzual	N-86,138.60, E-80,641.02 Clarines Coordinates	11,000	?	1948	Shell
Anzoatequi	Mene Grand	No. 1 Soto, District of Araqua	N-197,234.81, E-544,824.60 Barcelona Coordinates	10,892	Seisdel	1949	Mene Grande
Anzoatequi	Mene Grande	No. 2 Inca, District of Araqua	N-173,998.85, E-510,837.47 Barcelona Coordinates	6,990	SSC	1949	Mene Grande
Anzoatequi	Creole "A"	FX-1, District of Freites	N-191,189.28, E-545,775.41 Barcelona Coordinates	10,400	Gulf	1949	Mene Grande
Anzoatequi	Mene Grande	TM-6, District of Araqua	N-194,460.8, E-481,900.0 Barcelona Coordinates	11,760	Seisdel	1949	Mene Grande
Anzoatequi	Mene Grande	No. 1 Los Mangos, District of Freites	N-189,019.32, E-507,204.24 Barcelona Coordinates	8,325	Seisdel	1950	Mene Grande
Zulia	Mene Grande	No. 1 Poco	S-161,737, E-72,573 Maracaibo Coordinates	9,350	Seisdel	1949	Mene Grande

REVISIONS & CORRECTIONS

(corrections are in italics)

STATE OF CALIFORNIA

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County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
Orange	Standard	No. 2-1 Stern	7, 3S-10W	11,700	UGC	1946	CWVSG

County	Company	Lease	Location	Survey Depth	Shot by	Date	Sponsored by
			STATE OF KANSAS				
			Page 546 of Original Index Published in October 1944 *Geophysics*				
Ellsworth	Elwell et al.	No. 1 Springer	NE NW NW 35, 18S-10W	(*Remove from 1944 List*)			
			STATE OF LOUISIANA				
			Page 549 of Original Index Published in October 1944 *Geophysics*				
W. Baton Rouge	Amerada	No. 1 Wilbert	SE/4 26, 7S-11E	9,810	Petty	1941	*Amerada*
			Page 60 of Index Published in January 1949 *Geophysics*				
Rapids	Union Prod.	No. 1 Belgard	NE *cor. NW /4* 14, 4N-3E	9,804	*SEI*	1946	Union Prod.
			STATE OF MISSISSIPPI				
			Page 549 of Original Index Published in October 1944 *Geophysics*				
Jeff. Davis	Courson et al.	No. 1 Bailey	4, 6N-18W	*6,012*		*1940*	
			STATE OF OKLAHOMA				
			Page 553 of Original Index Published in October 1944 *Geophysics*				
Seminole	Shell	No. 1 Smith	*NW* NE NE 4, 9N-7E	*4,570*	Shell	*1942*	*Shell*
			Page 541 of Index Published in October 1946 *Geophysics*				
Garvin	Mid-Continent	No. 1 Menefee	SE SE SE 2, 4N-2W	6,345	Petty	1946	*Shell*
			STATE OF TEXAS				
District: East			Page 554 of Original Index Published in October 1944 *Geophysics*				
Hunt	C. D. Davis	No. 1 England	A-675 H. Marler Sur.	(*Remove from 1944 List*)			Stanolind
			Page 61 of Index Published in January 1949 *Geophysics*				
Cherokee	Standard	No. 1 New Birmingham Dev.	G. E. Looney Survey	*9,472*	WGC	*1948*	Standard
District: North			Page 556 of Original Index Published in October 1944 *Geophysics*				
Jack	Shell	No. 1 Carter	Blk. 3311, TE&L Sur.	*5,709*	Shell	1942	Shell
			Page 62 of Index Published in January 1949 *Geophysics*				
Jones	West Central Drlg.	No. 7-A Wimberly	NW 87, Blk. 126, DeWitt Sur.	5,642	*KVI*	1947	KVI
Montague	Magnolia	No. 1 Stowe	S. Stowe 84.67A, *P. Miller Sur.*	5,653	GSI	1946	Magnolia
District: Panhandle			Page 542 of Index Published in October 1946 *Geophysics*				
Hansford	Phillips	No. 1 Elton	Sec. 155, Blk. 2, G.H.&H. Sur.	7,597	*SSC*	1946	Phillips
District: West			Page 557 of Original Index Published in October 1944 *Geophysics*				
Andrews	Humble	No. 1 Kuykendall	*S. 24, Blk. 46, PSL*	4,086	Humble	1935	*Humble*
Gaines	*Gill et al.*	No. 1 *Crews*	Sec. 9, A-20, PSL	6,300	GRC	1934	GRC
			Page 542 of Index Published in October 1946 *Geophysics*				
Edwards	Shell	No. 1 Honeycutt	Sec. 7, TCRR Sur.	8,886	Shell	*1945*	Shell
			Page 557 of Original Index Published in October 1944 *Geophysics*				
			and Page 542 of Index Published in October 1946 *Geophysics*				
Irion	Shell	No. 1 Tankersley	Sec. 12, GC&SFRR	8,000	*National*	*1944*	*Shell*
			Page 62 of Index Published in January 1949 *Geophysics*				
Coke	Union of Calif.	No. 1 McCutchen	Sec. 444, Blk. 1A, H&TC Sur.	6,740	WGC	1947	*Union*
Ector	Stanolind	No. 1 Kayser	Sec. 34, Blk. 43, T2S, T&PRR	*12,585*	Texaco	1946	Texaco
			Page 63 of Index Published in January 1949 *Geophysics*				
Sutton	Humble	No. 2 *Meyer*	Sec. 40, Blk. EF, GC&SFRR	9,800	*NGC*	1948	*Humble*
			Page 66 of Revisions and Corrections Published in January 1949 *Geophysics*				
Dickens	Humble	No. 1 Matador Ranch	Sec. 26, *Blk. 1*, Shock & Arnold	7,030	Humble	1939	Humble
			STATE OF WYOMING				
			Page 542 of Index Published in October 1946 *Geophysics*				
Uinta	Mtn. Fuel Supply	No. 1 Church Buttes	SW NW 8, 16N-112W	12,850	Carter	1946	*RMSWSA*
			Page 542 of Index Published in October 1946 *Geophysics*				
			and Page 63 of Index Published in January 1949 *Geophysics*				
Carbon	Texas Co.	No. 1 *Unit (James)*	*NE SE SE* 35, 13N-92W	7,440	WGC	1945	RMSWSA
Carbon	Texas Co.	No. 1 Unit	NE SE SE 35, 13N-92W	(*Remove from 1949 List*)			

PATENTS

O. F. RITZMANN*

GRAVIMETRIC PROSPECTING

U. S. No. 2,523,075. R. C. Sweet. Iss. 9/19/50. App. 4/30/46. Assign. North American Geophysical Co.

Gravimeter. A gravimeter having a horizontal beam whose outer end is supported by a zero-length spring at an acute angle to the beam and with the other end of the beam supported by horizontal wires, nulling being accomplished by vertical adjustment imparted to the effective horizontal axis of the beam by means of an auxiliary spring.

MAGNETIC PROSPECTING

U. S. Ser. No. 571,484. C. M. Woodruff and B. L. Griffing. Publ. 8/22/50. App. 1/5/45.

Magnetometer. An electron beam deflection type of magnetometer using a barrier and a narrow slit in front of a dynode electrode in an oscillating circuit whose amplitude of oscillation is observed.

U. S. No. 2,518,513. R. D. Wyckoff. Iss. 8/15/50. App. 7/5/45. Assign. Gulf Research & Development Co.

Method and Apparatus for Measuring Magnetic Fields. A gyro-stabilized total-field magnetometer having on its outer frame flux-valve-controlled air jets which impinge on the gyro case to cause it to precess into the correct orientation and in which the flux-valves are sequentially excited.

U. S. No. 2,519,094. T. Zuschlag. Iss. 8/15/50. App. 10/30/45. Assign. Lundberg Explorations Ltd.

Apparatus for Detecting Magnetic Disturbances. A magnetic gradiometer having spaced, rigidly-connected, rotating coils connected to transformers whose secondaries are in opposition and their difference voltage analyzed with a variometer, potentiometer and c-r oscilloscope.

U. S. No. 2,520,677. R. E. Fearon. Iss. 8/29/50. App. 6/19/46. Assign. Stanolind Oil and Gas Co.

Magnetic Gradient Measurement. A flux-valve gradiometer having spaced cores each of which is excited at two frequencies and whose secondaries are connected in opposition and a modulation component indicated.

SEISMOGRAPH PROSPECTING

U. S. No. 2,513,314. J. E. Hawkins. Iss. 7/4/50. App. 10/9/47. Assign. Seismograph Service Corp.

Geophysical Prospecting System. A seismograph prospecting system in which positions are determined by radio and the indications of the radio position determining apparatus are recorded on the seismograph tape simultaneously with the shot.

U. S. No. 2,513,319. J. E. Hawkins. Iss. 7/4/50. App. 9/22/48. Assign. Seismograph Service Corp.

Geophysical Prospecting System. A seismograph prospecting system in which the elevation of stations is determined by radio and the indications of the elevation indicating apparatus are recorded on the seismograph tape simultaneously with the shot.

U. S. No. 2,515,456. G. B. Loper. Iss. 7/18/50. App. 3/20/46. Assign. Socony-Vacuum Oil Co., Inc.

Modulation-Free Gain Control System. An avc system using an electron-beam tube with a signal grid between a beam-forming cathode and the anode, and with beam-deflecting electrodes between the cathode and the grid which deflect the beam away from the grid.

* Gulf Oil Corporation, Patent Department.

U. S. No. 2,516,041. A. J. Abrams. Iss. 7/18/50. App. 3/26/46. Assign. Socony-Vacuum Oil Co., Inc.

Shothole Water Seal. A water seal for a seismograph shot hole having an expansible canvas bag on the lower end of a tubular container into which the explosive and water tamping is placed, the canvas bag being held folded in a collapsed form by bands which disintegrate when wet.

U. S. No. 2,521,130. S. A. Scherbatskoy. Iss. 9/5/50. App. 6/10/43.

Seismic Exploration by Means of Periodic Excitation. A variable-frequency continuous-wave seismic testing system using a sharply-tuned filter in the recording circuit and with the frequency of the earth vibrator and the tuning of the filter simultaneously adjusted by a single control.

U. S. No. 2,522,433. R. S. Dahlberg, Jr. Iss. 9/12/50. App. 10/24/57. Assign. Standard Oil Development Co.

Seismic Wave Transmitter. An acoustic logging or interval velocity logging apparatus having an electromagnetic vibrator at one end of a long rod and a geophone at the other, the driving frequency being continuously varied and observing the difference between the driving frequency and all frequencies picked up by the geophone.

WELL LOGGING

U. S. No. 2,515,500. R. E. Fearon, J. M. Thayer and G. Swift. Iss. 7/18/50. App. 6/23/48. Assign. Well Surveys, Inc.

Method and Apparatus for Producing Neutron Logs of Drill Holes. A neutron logging apparatus using a gamma-ray-free source of neutrons and a gamma-ray detector spaced from the neutron source, all exposed surfaces of the detector being made of a material which does not emit heavy particles when bombarded with neutrons.

U. S. No. 2,515,501. R. E. Fearon, J. M. Thayer and G. Swift. Iss. 7/18/50. App. 6/29/48. Assign. Well Surveys, Inc.

Neutron Well Logging. A neutron logging method in which the neutron source and gamma-ray detector are spaced a distance which is less than the average range of neutrons in the type of formation being logged.

U. S. No. 2,515,502. R. E. Fearon, J. M. Thayer and G. Swift. Iss. 7/18/50. App. 7/10/48. Assign. Well Surveys, Inc.

Neutron Well Logging. A neutron logging system whose source is a neutron emitter bombarded from a short-lived alpha rayer which is in secular equilibrium with a long-lived parent member of a radioactive series which is gamma-ray free, and in which the induced gamma-ray activity of the formations is indicated.

U. S. No. 2,515,534. J. M. Thayer, R. E. Fearon and G. Swift. Iss. 7/18/50. App. 6/23/48. Assign. Well Surveys, Inc.

Method and Apparatus for Producing Neutron Logs of Drill Holes. A method of neutron logging in which a gamma-ray-free source of fast neutrons is used with the borehole fluid replaced by carbon disulfide and gamma-rays from neutron-induced processes in the formations detected by an ionization chamber spaced from the neutron source.

U. S. No. 2,515,535. J. M. Thayer, G. Swift and R. E. Fearon. Iss. 7/18/50. App. 7/10/48. Assign. Well Surveys, Inc.

Method and Apparatus for Neutron Well Logging. A neutron logging apparatus using a neutron source and a gamma-ray detector having an ionizable gas and with all exposed surfaces of the detector made of a material which does not emit heavy particles when bombarded by neutrons from the source in the apparatus.

U. S. No. 2,515,745. G. Swift. R. E. Fearon and J. M. Thayer. Iss. 7/18/50. App. 4/8/49. Assign. Well Surveys, Inc.

Neutron Log. A neutron logging system using two sources and two detectors, one source producing neutrons and gamma rays and the second source producing only gamma-rays of the same energy as those of the first source, and recording the difference between the detector signals.

U. S. No. 2,517,455. H. C. Waters. Iss. 8/1/50. App. 12/26/44. Assign. Halliburton Oil Well Cementing Co.

Temperature Recorder. A temperature logging apparatus using a resistance thermometer in a 500-cycle bridge circuit in the well apparatus with the unbalance fed back up the cable as d-c, the well apparatus also having a 60-cycle operated stepping switch so that remote operations may be made with the bridge for zero setting, scale value, and calibration.

U. S. No. 2,517,603. D. Silverman. Iss. 8/8/50. App. 4/12/45. Assign. Stanolind Oil and Gas Co.

Fluid Ingress Well Logging. A method of permeability logging in which the motion of a water-oil interface is followed by an electrical-conductivity detector as oil is pumped into the well or as the pressure is oscillated.

U. S. No. 2,522,433. R. S. Dahlberg, Jr. Iss. 9/12/50. App. 10/24/47. Assign. Standard Oil Development Co.

Seismic Wave Transmitter. (See abstract under Seismograph Prospecting.)

MISCELLANEOUS

U. S. No. 2,513,314. J. E. Hawkins. Iss. 7/4/50. App. 10/9/47. Assign. Seismograph Service Corp.

Geophysical Prospecting System. (See abstract under Seismograph Prospecting.)

U. S. No. 2,513,315. J. E. Hawkins. Iss. 7/4/50. App. 10/9/47. Assign. Seismograph Service Corp.

Radio Position Determining System. A phase-comparison type of radio position-determining system using three spaced transmitters which radiate modulated carrier waves and receivers which indicate the phase of the modulation wave system and of the carrier wave system.

U. S. No. 2,513,316. J. E. Hawkins. Iss. 7/4/50. App. 10/9/47. Assign. Seismograph Service Corp.

Radio Survey System. A phase-comparison type of radio position-determining system using three spaced transmitters whose carriers are combined in a link unit which retransmits a combination wave with which phase synchronization may be established at the receiver.

U. S. No. 2,513,317. J. E. Hawkins and R. S. Finn. Iss. 7/4/50. App. 10/9/47. Assign. Seismograph Service Corp.

Radio Position Determining System. A phase-comparison type of radio position-determining system using three spaced transmitters one of which alternately radiates two frequencies which are received at the other two transmitters where they are respectively combined with the signal from the remaining transmitter.

U. S. No. 2,513,318. J. E. Hawkins and B. W. Koeppel. Iss. 7/4/50. App. 8/5/48. Assign. Seismograph Service Corp.

Radio Position Finding System. A phase-comparison type of radio position-determining system using three spaced transmitters one of which alternately radiates two frequencies which are received at the other two transmitters where they are respectively combined with the signal from the remaining transmitter, all signals being received at the mobile station where they are reduced to the same amplitudes and the phase compared.

U. S. No. 2,513,319. J. E. Hawkins. Iss. 7/4/50. App. 9/22/48. Assign. Seismograph Service Corp.

Geophysical Prospecting System. (See abstract under Seismograph Prospecting.)

U. S. No. 2,513,320. J. E. Hawkins. Iss. 7/4/50. App. 9/22/48. Assign. Seismograph Service Corp.

Radio Position Determining System. A phase-comparison type of radio elevation-determining system using two vertically-spaced transmitters each of which combines the signals from three broadcast transmitters and reradiates a combination signal with all signals picked up by the mobile receiver and the phases compared.

U. S. No. 2,513,321. J. E. Hawkins. Iss. 7/4/50. App. 11/27/48. Assign. Seismograph Service Corp.

Radio Location System. A radio position-determining system using three spaced transmitters which radiate pulse-modulated carriers and in which the mobile receiver is located by a combination of pulse travel time comparison and by phase comparison of the carriers.

U. S. No. 2,513,322. J. E. Hawkins. Iss. 7/4/50. App. 11/27/48. Assign. Seismograph Service Corp.

Radio Location System. A pulse-transit-time type of radio position-determining system using three spaced pulse-modulated transmitters one of which alternately radiates two frequencies which are received at the other two transmitters and combined with the signal from the remaining transmitter, all signals being received at the mobile station and their transit times compared.

SELECTED LIST OF U. S. PATENTS ISSUED DURING THE THIRD QUARTER OF 1950.

Patent No.	*Subject*	*Patent No.*	*Subject*	*Patent No.*	*Subject*
2,513,269	484	2,513,683	224	2,514,907	148
2,513,282	312	2,513,738	180	2,514,909	308
2,513,295	448	2,513,745	132	2,514,924	316
2,513,314[a]	312, 360	2,513,805	308	2,515,031	484
2,513,315[a]	312	2,513,818	140	2,515,034	332
2,513,316[a]	312	2,513,849	316	2,515,039	12
2,513,317[a]	312	2,513,962	316	2,515,154	484
2,513,318[a]	312	2,513,988	16	2,515,190	224
2,513,319[a]	312, 360	2,514,080	12	2,515,199	16
2,513,320[a]	312	2,514,081	484	2,515,200	16
2,513,321[a]	312	2,514,106	460	2,515,238	136
2,513,322[a]	312	2,514,135	308	2,515,332	316
2,513,329	180	2,514,250	16	2,515,446	484
2,513,340	16	2,514,355	44	2,515,456[a]	372
2,513,356	308	2,514,369	468	2,515,464	312
2,513,367	460	2,514,379	484	2,515,472	12, 436
2,513,388	88	2,514,434	32	2,515,500[a]	304
2,513,390	16	2,514,482	140	2,515,501[a]	304
2,513,398	392	2,514,492	180	2,515,502[a]	304
2,513,423	224	2,514,500	180	2,515,534[a]	304
2,513,478	316	2,514,541	16	2,515,535[a]	304
2,513,528	312	2,514,577	224	2,515,745[a]	304
2,513,531	136	2,514,578	224	2,515,762	420
2,513,616	224	2,514,633	324	2,515,780	136
2,513,617	224	2,514,677	316	2,515,785	484
2,513,653	224	2,514,690	168, 252	2,515,791	484

[a] Abstracted on preceding pages of this issue.

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2,515,888	68
2,515,957	484
2,515,969	180
2,516,015	324
2,516,041[a]	384
2,516,188	276
2,516,334	308
2,516,335	76
2,516,421	92
2,516,452	200
2,516,596	200
2,516,639	16
2,516,672	460
2,516,704	288
2,516,873	460
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2,516,982	108
2,517,038	288
2,517,121	420
2,517,138	484
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2,517,455[a]	452
2,517,469	308
2,517,540	316
2,517,560	48
2,517,603[a]	276
2,517,612	180
2,517,628	460
2,517,629	372
2,517,659	324
2,517,702	196
2,517,763	136
2,517,819	12
2,517,975	232
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2,519,180	68
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2,519,245	224
2,519,262	68
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2,519,360	484
2,519,366	316
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2,519,418	316
2,519,421	288, 136
2,519,422	16
2,519,591	160
2,519,592	224
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2,519,660	324
2,519,689	160
2,519,725	224
2,519,807	288
2,519,810	484
2,519,861	92
2,519,864	308
2,519,898	108
2,519,916	484
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2,522,522	304
2,522,530	484
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2,522,665	224
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Patent No.	*Subject*	*Patent No.*	*Subject*	*Patent No.*	*Subject*
2,522,870	484	2,523,075[a]	180	2,523,576	224
2,522,877	484	2,523,288	316	2,523,775	484
2,522,880	316	2,523,295	312	2,523,779	308
2,522,902	308	2,523,341	484	2,523,802	484
2,522,924	140,12	2,523,464	428	2,523,858	316
2,522,927	140	2,523,474	4	2,523,866	160
2,522,988	200	2,523,515	484	2,523,895	312

REVIEWS

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Outline of Radio, Television and Radar by R. S. Elven et al., Chemical Publishing Company, Brooklyn, New York, 1950. $12.00. 688 pp.

This book is the joint product of eight British authors. The preface states, "The object of the present book is to provide a readable and up-to-date outline of the principles upon which the whole science of radio is based; to show how the necessary components of a radio circuit are designed to fulfill the theoretical requirements; and to deal with radio-frequency amplification, detection, the principles of superheterodyne receivers, automatic volume control, low-frequency amplification, and the output side.

"The special technique which is necessary when working with short and ultra-short waves is fully described, as are also television, radio direction finding, and radar."

This objective is fully attained. The treatment is essentially non-mathematical throughout. However, even though the tone is elementary, advanced topics are covered in an adequate manner. The first five chapters, requiring only knowledge which is possessed by even the non-technical reader, cover the nature, production, use and measurement of electricity and radio waves. The next five cover components, discussing their theory and practical construction. The next ten chapters give a clear picture of vacuum tubes and the related circuits in radio receivers, including batteries, loud-speakers, microphones and phonograph pickups. Then follow a chapter on short wave technique, three on television and two on radio direction-finding and radar.

Since this book is intended as an outline, the expert will find nothing new in his own field. The novice will, however, find it helpful and readable. Even the expert may enjoy some of the skilled explanations. The British origin of the material is obvious in the terminology, the choice of illustrative materials and in some techniques, such as the reversed sign of video modulation in TV leading to the use of the "black spotter." It is doubtful whether any of these deviations from American practice will confuse any reader.

W. M. RUST, JR.
Humble Oil & Refg. Co.

La Prospection Geophysique, by Louis Cagniard, Presses Universitaires de France, Paris, 200 pp. (1950).

Of all the books on geophysical prospecting that have appeared since the birth of the art, this 200-page French monograph is the first to have been written primarily for the non-technical reader. Neither a text-book nor a treatise, this book is designed to serve as an introduction to the subject for "all those, such as miners, geologists, oil men, engineers, and investors who need to have an over-all view of the services that geophysical prospecting can and should render." It is also intended for students or future students who are considering geophysics as a career as well as for any one who has a particular interest in "discovering things that are concealed."

An audience this diversified imposes drastic limitations upon the mathematical level at which such a subject can be treated. The author, although a distinguished French applied mathematician,

meets this difficulty by omitting all mathematics except for a very few equations. He remarks in the preface that his mathematician friends will probably reproach him for trying to do in words what can be done much more briefly and precisely by mathematical formulas. "I hope," he goes on to say, "that these same mathematicians will pardon me when they note the pains I have taken to explain the fundamental principles of petroleum geology to them in language which may appear too simple to the professional geologist."

The book consists of six chapters. The first is a general discussion of geophysical prospecting. The next four are devoted, respectively, to the gravitational, magnetic, electrical and seismic methods. The last chapter takes up various less established prospecting techniques such as the thermal, radioactive, geochemical and geobiological. Of the chapters dealing with single geophysical methods, the longest (41 pages) is on gravity while the shortest (23 pages) is on magnetic prospecting. In spite of this brevity, Cagniard manages to give a surprisingly complete discussion of each method, covering basic theory (to the extent that he can without using much mathematics), instrumentation, field procedure, interpretation, and applications.

Cagniard's treatment of geophysical prospecting shows him to have a more thorough practical and up-to-date knowledge of all its branches than one person is usually able to acquire in the present age of specialization. In spite of this, he has a tendency to dwell excessively on more or less abstract matters having little direct connection with prospecting. His gravity chapter, for example, begins with a long discussion of fixed vs. moving axes, inertial vs. gravitational forces as illustrated by d'Alembert's equation, and other topics which require more background in analytical dynamics than the average reader for whom the book is intended is likely to have. In this connection, there is some doubt in the reviewer's mind whether a book devised for the non-technical reader should make use of vector notation and calculus in the few instances where mathematical formulas are presented. Perhaps the educated layman in France is more likely to have studied these subjects at school than his counterpart in this country.

The book has few diagrams or illustrations and no references whatsoever. The omission of a bibliography is somewhat deplorable in a book of this type since many readers after being introduced to the subject might wish to pursue some phases of it further.

The best part of the book is the introductory chapter. This is essentially an essay on the philosophy of geophysical prospecting, with many thought-provoking epigrams that the professional geophysicist should find particularly stimulating. The author, for example, makes contemptuous reference here to geophysicists, particularly "authors of treatises on prospecting who have never prospected for anything not in a library," who catalogue the anomalies to be expected from bodies having a great number of simple geometrical forms and who try to interpret *all* anomalies observed in the field by reference to their catalogue. He discusses at some length the differences between prospecting for oil and prospecting for minerals. Much of the difference, he points out, is in attitude and approach, both of which are based on economic considerations. Remarking that the best field magnetometers have not been appreciably improved in precision since 1918, he points out that "if the geophysicist had decided to attack the problem of the (magnetic) variometer seriously, if he had applied to this only a part of the zeal which was consecrated to the perfection of the gravimeter, there is no doubt that the sensitivity of this apparatus would very soon have been multiplied by a factor of ten and the possibility of using the magnetic method for mineral prospecting would have increased a hundredfold."

It is hoped that Cagniard's little book will be translated into English. It should benefit not only the non-specialists for whom he expressly wrote it, but should be valuable as a review and source of new ideas to practitioners of the art as well.

MILTON B. DOBRIN

Prospection Geophysique, by Edmond Rothé et J. P. Rothé, Tome 1, Gauthier-Villars, Paris, 1950.

This volume supplements an earlier book of Edmond Rothé: *Les Methods de Prospection du Sous-Sol*, and covers developments in applied geophysics since 1930. Volume 1 treats seismic methods and radioactive methods by ionization techniques. Volume 2 will be devoted to gravimetric, magnetic,

electrical, and geothermal methods. Each method of prospecting is presented in two chapters, one developing pertinent theory and describing apparatus, the other giving detailed examples of applications taken from actual field investigations.

Seismic methods are described in a chapter which covers 136 pages. The sections on refraction are brief, being devoted mainly to curved ray paths and dipping beds. Most of the developments in seismic prospecting since 1930 have been in reflection techniques, which are adequately covered in the greater part of the chapter. A novel feature is a section on amplitudes applying formulae used in earthquake seismology. A large section is devoted to a description of apparatus, including a complete discussion of the theory of the recording system from pick-up through amplifier to galvanometer. Little material on actual field procedure, such as criteria for determining detector spread, use of multiple detectors, etc. is presented.

The chapter on applications of the seismic method is a unique feature of the volume. In 145 pages the authors give case histories illustrating typical applications of seismic methods in the United States and in Europe. Several sections are devot d to examples of applications to structural research, glacial investigations, and suboceanic studies.

The chapter on radioactive methods by ionization techniques discusses in 104 pages methods of prospecting, laboratory measurements, apparatus, and includes many tables and graphs. Geological applications of radioactive methods are described in a concluding chapter of 146 pages. Studies of faults, stratigraphic correlations, and prospecting for contact zones and veins are discussed. Particular emphasis is on the researches of the late senior author and his collaborators. Only a brief section of 7 pages is devoted to radioactivity well logging.

Prospection Geophysique is particularly suited for use as a supplementary textbook. It differs from existing books in English in that a large proportion of the text is devoted to examples or case histories from commercial exploration and geological research in the United States and Europe. An extensive bibliography covering material published through 1949 follows each section and should be particularly useful.

FRANK PRESS
Lamont Geoglogical Observatory
Columbia University

Subsurface Geologic Methods, 2nd Edition, Compiled and Edited by L. W. Leroy, Colorado School of Mines, 1950, 1156 pages.

The first edition to this compendium was reviewed in some detail in the January 1950 issue of *Geophysics* and the statements made there also apply essentially to the second edition. However, the present edition has been enlarged by over 300 pages and contains considerable additional information in many of its diversified sections, as well as including several new sections on such subjects as Secondary Recovery Methods, Evaluation of Petroleum Properties, Geochemical Methods, Micrologging, Drill Stem Testing, Mud Chemistry, Cementing Problems, Acidization, Shale Density Analysis, and Graphic Methods in Mining. In addition, a series of questions at the end of each chapter has been added as an instructional aid, and an index is now included.

It is impossible to describe the entire gamut of subsurface geologic and associated methods with any degree of detail or completeness even in a volume of over 1,000 pages. However, this book represents an important contribution to the field because it presents, between two covers, at least the nomenclature and high lights of the diversified methods and techniques used in the exploration for and the production of oil. Perhaps one of the chief values of such a book lies in the ability of someone familiar in great detail with one or more of the various phases of subsurface geologic and allied techniques to become familiar with at least the terminology and some of the fundamentals of other phases of knowledge in this broad subject. The reviewer is somewhat surprised by the omission of the periodical *Geophysics* from the group of allied periodicals listed in the preface to this book, particularly when the large majority of the references and illustrations in the section entitled "Subsurface Methods as Applied in Geophysics" is taken from *Geophysics*.

R. A. GEYER

Gerlands Beiträge zur Geophysik, Band 61, Heft 2 (1949) and Heft 3 (1950), Leipzig.

After an interruption of many years caused by war and postwar conditions in Germany, *Gerlands Beiträge zur Geophysik*, long recognized as one of the world's foremost geophysical journals, has resumed publication. The first two issues to appear since its rebirth have reached this country, but copies are hard to obtain because of presently restricted exchange of literature with the Russian zone of Germany, where it is edited and published.

According to a note by the editor, R. Bock, on the first page of the first postwar number, this is the only journal in Germany currently devoted to geophysics. For this reason several changes in policy are announced. Papers are solicited in applied as well as in pure geophysics. In addition to original scientific papers, less formal communications will also be published. In this way, the editor hopes to make the contents more "lively" than heretofore.

Papers in these two issues are concerned both with pure and applied geophysics, the majority belonging to the former classification. Most of the applied papers are mathematical and are concerned with gravity effects from bodies of various shapes. Others deal with the torsion balance data and with the theory of electromagnetic prospecting. It would be interesting to know whether the dearth of more up-to-date subject matter pertaining to geophysical prospecting signifies a lack of interest and activity or simply an unwillingness to publish on the part of those sponsoring whatever geophysical work is going on in the Russian zone.

MILTON B. DOBRIN

On the Isostatic Structure of the Earth's Crust, By W. Heiskanen. Publication of the Isotatic Institute of the International Association of Geodesy, No. 24. (Reprinted from the *Annales Academiae Scientiarum Fennicae*, Ser. A, III, *Geologica-Geographica*, 22).

W. Heiskanen is Director of the Isostatic Institute at Helsinki, and this publication "contains the principal part of . . . 'Report on Isostasy,' written for the Oslo General Assembly of IUGG in 1948." Nine subjects are covered in this report. These are:

"1. The usual reduction methods of the gravity values.
2. The standard reduction.
3. The isostatic reduction maps.
4. The geological correction of the gravity anomalies.
5. Some studies of the gravity formula.
6. The geoid studies.
7. The gravimetric method for computing the deflections of vertical.
8. The isostatic reductions of the gravity values.
9. The isostatic study of some interesting regions."

Some of the material covered in this report has necessarily been published elsewhere, especially "The isostatic study of some interesting regions." The subjects previously discussed are not referred to in this review, only new ones being covered here.

Under the heading, "The usual reduction methods of the gravity values," the reader discovers that there is much doubt about the isostatic, geological and indirect-effect reductions. One can readily understand Heiskanen's concern with the whole question of isostasy when students of the calibre of Jeffreys consider isostasy as fictitious. Heiskanen, however, clearly illustrates the need for making this reduction. Among the points he makes are:

(1) This reduction alone eliminated the general presence of negative Bouguer values in mountainous areas and positive values of the ocean basins.

(2) Use of isostatically corrected values of the deflections of the vertical has resulted in a good value for the figure of the earth.

(3) The isostatic reduction eliminates to a large degree the errors caused by choosing the wrong value for the density of the surface rocks in making the Bouguer reduction. Choice of the correct

density value is quite controversial. H. S. Washington arrived at a figure of 2.79. The most commonly used figure of 2.67 is, on the contrary, too large, according to Bullard. The geological correction discussed subsequently is actually an attempt to correct for an erroneous density.

Some geodesists propose that even the Bouguer reduction is not necessary because of isostatic compensation. They recommend only a free air reduction, which is saying, essentially, that the isosta ic depth of compensation is zero. This method is at best applicable, however, only in level areas where the isostatic correction is smooth and small. In conclusion, therefore, Heiskanen proposes that the Airy system of isostatic compensation be universally adopted, utilizing a depth of 30 km. and a density contrast of 0.6 between crustal and subcrustal materials.

The correction for the indirect-effect is the one for reducing to a compensated geoid, and its values range from $+10.3$ to -3.4 mgal. Heiskanen concludes, however, that this whole question is "in the air," after studying the views of leading geodesists such as Lambert, Vening-Meinesz and Lejay, who seemingly cannot agree on whether or not compensating masses need themselves to be compensated.

The geological correction is brought to the fore by the work of Woollard in the Rocky Mountains and the work of Evans in Burma. This particular correction seems, to the reviewer, to be somewhat paradoxical. It is almost a question of how to interpret a "regional residual" anomaly, if a phrase may be coined. That is to say, if in the course of gravitational studies on a nation-wide or continental scale one is left with a residue which he cannot explain away by means of the usual reductions, he then looks to the local geological conditions to see if therein lies an explanation. For example, a thick section of light sedimentary deposits in a basin might account for a negative residue. So the geological correction is actually an attempt to explain away a residue in terms of known abnormal geological conditions or to suggest that such conditions might be present if they are not heretofore known. In either case, especially the latter, the so-called correction might better be termed a "solution."

It is of interest to note that Heiskanen gives his approval to the International Formula as devised in 1930. The one possibility of drastically changing the formula is that of setting it on an entirely new datum. All evidence accumulated so far suggests that the Potsdam datum is too high by about 15 mgs. Morelli, Jeffreys, Berroth, and Woollard arrived at a correction of this magnitude. Woollard's conclusion is based on his world-wide airplane journeys during which he endeavored to tie together all the major pendulum values of the globe. Heiskanen gives full appreciation to Woollard's efforts and suggests, as a further continuation of this work, that similar loops be made in Europe, North America, South America and Southeast Asia, employing two or more gravimeters.

NELSON C. STEENLAND

"Eszköz a földi mágneses ter gradiensének meghatarozasára." ("An instrument for the determination of the gradient of the earth's magnetic field") by Ernö Ács. *Földméréstani Közlemények (Geodetic Publication,* previously: *Communication of the Hungarian State Survey)* Vol. II, pp. 24–34.

In the first part of this article the author shows that the accuracy of the commonly used field magnetometers is not sufficient to detect relatively small ore bodies which are of economical importance in Hungary. As an increase in the accuracy of the magnetometer would not be practical, a new kind of instrument should be devised, the accuracy to be a few magnitudes higher than that of the magnetometer, the data measured with it to be free of diurnal variations and to furnish a better picture of the structure of the magnetic field. The author believes that these aims may be fulfilled by an instrument measuring the gradient of the magnetic field. This instrument can be highly sensitive; the diurnal variations do not affect the magnetic gradient; and a small number of gradient values observed in limited space (such as in mines) can be interpreted more efficiently than the same number of magnetic intensity values.

In the second and third parts the principles are given of an instrument for measuring the gradient of the earth's magnetic field. It is assumed that the earth's magnetic field changes linearly within

the instrument. A plane figure circuit is rotated around an axis normal to this plane. It is shown that under the above conditions the electromotive force

$$V = \frac{d\phi}{dt} = f\left(\frac{\partial Z}{\partial x}\cdot\frac{dx_c}{dt} + \frac{\partial Z}{\partial y}\cdot\frac{dy_c}{d^6}\right)$$

where ϕ is the magnetic flux through the area f of the plane figure, Z the component of the magnetic field intensity normal to the plane of the circuit, x_c, y_c coordinates of the center of the plane figure, and t is time. ($\partial Z/\partial x \cdot dx_c/dt$ and $\partial Z/\partial y \cdot dy_c/dt$ are scalar products of vectors.) Consequently, knowing the velocity of the center of the circuit and measuring the induced electro-motive force, components of the magnetic gradient, in the plane of the circuit can be determined. By making observations in three different planes the values of

$$\frac{\partial X}{\partial x};\ \frac{\partial X}{\partial y} = \frac{\partial Y}{\partial x};\ \frac{\partial X}{\partial z} = \frac{\partial Z}{\partial x};\ \frac{\partial Y}{\partial y};\ \frac{\partial Y}{\partial z} = \frac{\partial Z}{\partial y} \quad \text{and} \quad \frac{\partial Z}{\partial x} = -\frac{\partial X}{\partial x} - \frac{\partial Y}{\partial y},$$

and thus the magnetic gradient can be computed from the measured data.

Two semicircular conductors can be used, one end of each connected, the other ends attached to connectors mounted on the axis passing through the center of the circle containing the two semicircles. The voltage induced in these semicircles when rotated, is measured in the instances when the connectors alternately touch the end posts placed in directions forming a right angle at the axis. The output voltage can be amplified and measured with an accuracy of 1×10^{-7} volts which corresponds to an accuracy of about 1γ/km (10^{-10} oersteds/cm) with an instrument of practical dimensions (radius of semicircle 30 cm, number of turns 10, 6000 rpm).

The author seems to be unaware of the fact that surface effects may cause irregularities in the gradient which are a few orders of magnitude greater than the intended accuracy of the instrument. Because measuring the voltages obtained through connections of very short duration between the connectors mounted on the axis and the end posts is subject to errors, it is suggested that the two semicircle conductors be replaced by an aluminum disc with two semicircles cut out of it (actually a ring with a connection along a diameter); and the electromotive force be measured by the induction in coils placed parallel to this revolving disc. Self inductance and mutual inductance should be considered. After writing the article the author built an experimental model which proved the practicability of measuring the electromotive force by induction in the revolving double semicircle.

The fourth part of the article deals with the possible sources of error and the author concludes that the only serious problem to be considered is the inaccuracy in the orientation of the individual windings of the coil with respect to the axis and the changes in the orientation of the same during the observations due to mechanical forces created by the rotation.

RAOUL VAJK
Standard Oil Co., (N.J.)

"The Elevation Correction of Anomalies," by L. Egyed. *Földtani Közlöny*, vol. 79, nos. 1–4, pp. 94–111 (1949). In English with Hungarian abstract.

The subtitle is "The Determination of Vertical Gradient of Anomalies by Means of Gravity Meter and Torsion Balance Measurements"; this describes this paper accurately. The purpose of computing the vertical gradient effect for gravity anomalies is to use it to correct these anomalies down to a reference level (such as sea level). This type of correction may be important in questions of isostasy or other large scale geologic problems.

For flat areas the author presents a simple expression for the change in the vertical gradient between two points; this uses the derivatives of the torsion balance curvature components along two perpendicular axes in the horizontal plane. The formulas used come from a paper by T. Olczak, "The Measurements with the Eötvös Torsion Balance and the Problem of Determining the Higher Normal Derivatives of the External Gravity Potential" (in Polish with an English abstract, *Inst. Géol. de*

Pologne, Bull 45 *Série Géoph.*, Warsaw, 1948). To determine the absolute value of the vertical gradient, the author presents a method which uses gravimeter as well as torsion balance data. This will not be discussed here since, with the declining use of the torsion balance, the details would interest only a few who undoubtedly would consult the original paper.

If a good gravimeter survey is available, the reviewer believes that the most practical method of transferring a gravity anomaly to a lower level is the continuation downward process given in the recent paper of Leo J. Peters, "The Direct Approach to Magnetic Interpretation and its Practical Application," *Geophysics*, 14, pp. 290–320, July, 1949. However, it is gratifying to notice the increasing interest in the computation of higher derivatives of the gravity potential as evidenced by this paper and also by the recent one of B. F. J. Kunz, "Die Bestimmung des Vertikalen Schweregradienten," *Österreichisches Ingenieur-Archiv*, 2, pp. 1–17, 1947, which describes closely related work.

THOMAS A. ELKINS
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"The Experimental Determination of the Geomagnetic Radial Variation," By S. K. Runcorn, A. C. Benson, and A. F. Moore. *The Philosophical Magazine*, Vol. 41, 7th Ser., No. 319, pp. 783–791, (August, 1950.)

Two types of theories have been advanced to account for the dipole components of the geomagnetic field. One type has been designated the Distributed Theory and stems from the fact that the "axial dipole component . . . might be a fundamental property of any rotating spherical mass." The second, the Core Theory, has been developed from a "flow of electric currents . . . confined to the deep interior of the earth."

The designations themselves intimate that the two types have anomalous radial components. Runcorn and Chapman, in 1948, calculated "the differences (ΔZ, ΔH) between the vertical and horizontal field components (Z_2 and H_2 respectively) at a small depth 'd' below the earth's surface and the vertical and horizontal components (Z_0 and H_0 respectively) at the surface. They showed that though for a Core Theory, if R is the radius of the earth,

$$\Delta Z = Z_d - Z_0 = + (3.0d/R)\, Z_0$$

and

$$\Delta H = H_d - H_0 = + (3.0d/R)\, H_0$$

a Distributed Theory, assuming the density of the surface rocks is 2.7, gives

$$\Delta Z = Z_d - Z_0 = + (3.0d/R)\, Z_0$$
$$\Delta H = H_d - H_0 = - (6.5d/R)\, H_0 \cdots$$"

The authors present their attempts at obtaining experimental data on geomagnetic radial variation. Data were obtained by measuring the vertical and horizontal components in three mine shafts where the value of d was of the order of 3,000 feet. The results are repeated below.

Theoretical ΔZ Both Theories	Experimental ΔZ	Theoretical		Experimental ΔH
		ΔH Core	ΔH Dist.	
+16*	+11±3	+6	−13	+22±2
+19	+11±3	+8	−16	+ 7±2
+18	+18±3	+7	−15	+10±3

* Values in gammas. "+" denotes increase with depth.

The tabulated results obviously favor the Core Theory, if only because no negative ΔH's are observed.

An investigation of this type must necessarily account for radial variations arising from other sources, primarily those originating from local magnetic anomalies and those from the experimental techniques. Unfortunately, this particular report omits the detailed experimental results which are to be reported elsewhere. These aspects are discussed, however.

First of all, the investigations were conducted where the basement rock was at a depth of 8,000 feet. Thus the large basement effects were smoothed. The sedimentary section was sampled and susceptibilities measured. These were somewhat high for sediments, ranging from 11.7×10^{-6} to 69.7×10^{-6}.

The vertical and horizontal components were surveyed on the surface. Linear surface gradients of these components were derived from the maps and used to determine the radial correction for basement anomalies. The corrections, not tabulated, were described as "small." Linear gradients have commonly been found to be closer to fiction than fact even with a buried basement. The linear portion of a basement anomaly ordinarily extends over a horizontal distance having a magnitude of the depth of burial, 8,000 feet in this case. A more practical method for determining the variation of an anomaly with depth would be the continuation process, especially if the sediments were less susceptible than in this case and therefore more reasonably neglected.

The sedimentary effect was computed for the various beds, whose horizontal extent was unknown. Two effects were calculated, a "maximum" (18 gammas for 4,000 feet) and an "average" (6 gammas for 4,000 feet). The average effect was considered "more realistic" although it hardly seems so when defined as "an average value . . . produced by beds of all sizes up to a certain arbitrary maximum."

The instruments used were LaCour's magnetometric zero balance and his quartz horizontal magnetometer. Measurements were stated to be accurate to one gamma. The systems had temperature coefficients of 10 gammas per degree C, so careful work was mandatory to say the least.

Careful analysis of the omitted detailed results would be needed before these data could be accepted. Meanwhile, consideration may be given toward carrying on these experiments under more favorable conditions. A deep borehole together with a fluxgate magnetometer would possibly have the advantages of greater d values, a continuous and more accurate record, a deeper basement, a sedimentary section with the susceptibility less than 10^{-5}, and much less artificial interference than is usually encountered in a mining area.

NELSON C. STEENLAND

"Comparison of Field and Laboratory Measurements of Seismic Velocities in Sedimentary Rock" by Charles W. Oliphant, *Bull. Geol. Soc. Am.*, Vol. 61, pp. 759–787 (1950).

During the past two decades geophysicists endeavoring to identify rock materials within and beneath the earth's crust on the basis of seismic velocities observed in the field have turned increasingly to laboratory measurements of rock velocities. By comparing speeds of different rock samples determined in the laboratory at pressures and temperatures corresponding to various depths within the earth with speeds calculated for the same depths from earthquake and quarry blast seismograms, they have arrived at some plausible inferences regarding the constitution of deep crustal and subcrustal layers. This work has of course involved igneous rocks almost entirely. The purpose of Oliphant's research, carried on under the auspices of Harvard University, was to apply the same method to the investigation and identification of near surface sedimentary rocks. As a test of its applicability, experiments were conducted on the same rock material in the field and in the laboratory.

The author first measured longitudinal and transverse velocities of seismic waves from shot-hole explosions in some shallow formations in Osage County, Oklahoma, using standard refraction techniques. He obtained core samples from several of the formations, all limestones, and measured their longitudinal and transverse velocities with apparatus previously used by Birch for measurements mainly on igneous and metamorphic rocks. Significant differences were found between results in the field and in the laboratory.

Longitudinal speeds were obtained with little difficulty from first arrival times of waves traveling vertically up boreholes, to a depth of 3,700 feet, and horizontally along refraction paths. Transverse

events could not be identified at all on the records of the uphole shots and could be recognized only with difficulty on the traces from the horizontal profile. Criteria were developed for picking first shear arrivals on the latter records. These were based on theoretically determined relations between the three components of motion recorded on separate traces.

The near-surface geologic section could for purposes of seismic interpretation be treated as three layers of distinct seismic speed separated by horizontal discontinuities. The deepest layer penetrated by the refracted waves was the high-speed Neva limestone, whose top occurred at about a 240-foot depth. The comparisons between velocities determined in the field and in the laboratory were confined principally to the consolidated Neva limestone.

In the laboratory tests core samples from one of the shot holes were set into forced vibration at continuously varying frequency until resonance was noted, the velocity being calculated readily from the resonant frequency. The apparatus was so designed that it could produce either longitudinal or torsional vibration, the former giving compressional speed, the latter, transverse speed. An effort was made to correct the results to the pressure, temperature, and water content of the Neva limestone in place.

A bimodal distribution of compressional and shear velocities was obtained from the laboratory measurements on 17 test specimens of Neva limestone. It suggested that the formation comprises two types of thin alternating layers about a foot thick. Some question may arise as to the reliability of such an apparent distribution based on so few samples. The fact that the transverse velocity in the field agrees with the laboratory value for one type while the longitudinal velocity agrees with that for the other suggests to the author that the two waves took different paths and that the excessively low Poisson's ratio calculated from the field data has no significance. The results illustrate the difficulty to be expected in correlating field and laboratory measurements of elastic properties even in well consolidated sedimentary rocks. The limitations of this technique as an aid in identification are thus pointed out.

An interesting by-product of the investigation was the conclusion that SH type transverse waves are not generated at the shot but result from partial transformation of longitudinal waves at the irregular base of the weathered zone.

Oliphant's experiments provide some valuable data on the relation between the "microscopic" and "macroscopic" elastic behavior of sedimentary rocks. A few minor points in his paper appear questionable. The response curve for the seismograph shows a peculiar discontinuity in slope at about three cycles which if real might cause some distortion in the recorded surface waves. The five-figure precision in horizontal speeds indicated on the cross sections could not have been justified by the data, even though the speeds were obtained as least-squares solutions. The surface waves shown in the sample records were interesting and exhibited dispersive characteristics that, if analyzed, might have cast additional light on the shear velocities in the surface layer and substratum. Further experiments of this type comparing field and laboratory results for other sedimentary formations and other subsurface geometries should go far toward giving fundamental information on seismic wave propagation that might be of benefit in seismic prospecting.

MILTON B. DOBRIN

"Variation of Elastic Moduli of Igneous Rocks with Pressure and Temperature" by D. S. Hughes and H. J. Jones, *Bull. Geol. Soc. Am.*, Vol. 61, pp. 843–856 (1950)

The standard technique for measuring the seismic speeds of rock samples in the laboratory has been to set the sample into forced vibration and determine the frequency at which resonance is observed. This procedure was employed in the study of sedimentary rocks discussed in the preceding review. The method breaks down, however, when one attempts to measure longitudinal velocities under confining pressure, and transverse speeds can be obtained only with difficulty. The present paper describes a more direct method for measuring both kinds of velocity using recently developed microwave pulsing techniques. This method appears to lend itself much more readily to work at elevated pressures than does the indirect resonance method.

The technique consists of applying a high amplitude (800 volt) pulse over a tenth of a microsecond interval to a quartz driving crystal at one end of a rock cylinder two to four inches inches long and to receive the pulse with a similar crystal at the other end. The travel time is measured with an accuracy of five hundredths of a microsecond by a cathode ray oscilloscope with circular sweep. Additional pulses can be identified which have traveled obliquely across the sample at transverse speed and the travel time for these also makes it possible to compute transverse velocities. The sample and crystals can be subjected to hydrostatic pressure up to about 1050 kg/cm² and to temperatures as high as 150 C. Thus conditions corresponding to a depth as great as 4000 meters can be reproduced.

Using this equipment, the authors obtained data on the elastic properties of five types of rock: granite, andesite, quartz monzonite, diorite, and norite. Longitudinal and shear velocities were obtained for these over a pressure range of from 35–1022 kg/cm² and at temperatures between 30–158 C. The effect of fluid penetration was investigated by comparing speeds for samples jacketed in copper foil with those for corresponding samples in direct contact with the oil at elevated pressures. The enclosed samples show rapid increase of velocity with pressure at lower pressures, the rate tapering sharply at pressures above 500 kg/cm². The open samples show a much slower, more uniform increase over the entire pressure range. Penetration of fluid into the rock in the latter case prevents the closing up of pore spaces that occurs when the jacketed sample is subjected to pressure.

The authors state that they have begun to study velocities in sedimentary rocks with the same type of apparatus in the same pressure range. It is interesting to observe that Oliphant (see previous review) investigated the applicability of similar equipment at Bell Telephone Laboratories for measuring the velocities in his Neva limestone samples as well as some specimens of Quincy granite. A prohibitive amount of attenuation was encountered when wave lengths approached the grain size of the rock; and lower frequencies were recommended for coarse-grained sedimentary rocks than would ordinarily be used for igneous specimens. Reports on this more recent phase of the work should be particularly interesting to those working in applied geophysics.

MILTON B. DOBRIN

"Shooting Oil and Gas Wells," by B. F. Grant, W. S. Duvall, L. Obert, R. L. Rough, and T. C. Atchison, *Oil and Gas Journal*, Vol. 49, No. 4, pp. 65–73 (1950).

This paper describes current research by the U. S. Bureau of Mines correlating the strain waves produced in rock by explosions in shallow drill holes, the change in fluid conductivity around the shot holes, and the physical properties of the rock. The results presented do not establish a correlation between shot characteristics and fluid conductivity, serving rather as a basis for future experiments. However, the strain wave forms themselves should be of interest to anyone working with small explosions in the ground.

As a part of the investigation, physical properties of the rocks were measured using cores from the site of the explosive tests. This combination of wave form studies and adequate elastic information is all too rarely found, and it is hoped that further publications of this nature will be forthcoming

The radial strain wave forms consist of a rapid rise to a peak of compressive strain, followed by a tensional strain of smaller magnitude and longer duration. Change in wave form with distance shows reduction in high-frequency content. The peak compressive strain was found empirically to give an approximate fit to the following relation:

$$\epsilon = k(W^{1/3}/D)^n$$

where

ϵ = maximum compressive strain in micro-inches per inch
k = 12,000
W = charge size in pounds
D = distance from shot in feet
n = 5/2

No physical basis was given for using a relation of this form. A plausible alternative is:

$$\epsilon = ke^{-AD}/D$$

It is felt that the scatter in the experimental points would permit fitting the data to this relation by suitable choice of k and A.

The authors appreciate the equal usefulness of measuring pressure or particle motion rather than strain even though their experiments with the former type of measurement were unsuccessful. Two curves are included showing very poor results when accelerometers were used to detect the wave. These results do not indicate a basic limitation of motion-sensitive devices, and the ease with which such detectors can be planted in drill holes is a strong point in their favor. Strain gauges must be cemented to cores which then must be re-cemented in the drill holes, a laborious and apparently a somewhat uncertain process. Two reports on this general program have been issued in Bureau of Mines Reports of Investigations 4581 and 4683, which are highly recommended as extensions of the article reviewed here.

J. E. WHITE
Magnolia Petroleum Co.

"Velocidad Aparente de Propagation de las Ondas Sismicas Longitudinales" (Apparent Velocity of Propagation of Longitudinal Seismic Waves) by Juan M. Lopez de Azcona, *Travaux Scientifiques*, Serie A, Fasicule 17, Publication du Bureau Central Seismologique International, pp. 17–56 (1950)

This article is based on almost 20 years of refraction seismograph shooting by the Geophysical Section of the Spanish Government's Mining and Geological Institute. The 496 kilometers of line appear to be well scattered throughout the geologic section encountered in Spain. The velocities which have been measured are the horizontal velocities, the author mentions no well shooting which would give the vertical velocities needed for reflection depth computation. The equipment used consisted of two sets of seismographs; one was manufactured by Ambronn, the other, of the Mintrop type, by Askania.

Although only conventional refraction shooting was used in the field work, the author claims that he has measured horizontal velocities of low velocity beds normally lying below higher velocity beds. On almost all of the prospects, velocity values are given for marl, shale, and sand beds lying below limestone, salt, or anhydrite. It is presumed that the entire section was outcropping in the area, and that lines were so located as to find the low velocity sections where they appear on the surface.

The extreme variability of horizontal velocities is pointed out and reasons are given why this should be the case. Radical examples are given of how much the apparent velocity changes between up-dip and down-dip shooting along the same formation. One point would be rather surprising if it can be confirmed. Lopez de Azcona maintains that if a thin, normally low velocity bed is sandwiched between two thick high velocity layers, the thin bed will give a refraction event having a lower than normal apparent velocity. Conversely, a thin high velocity bed sandwiched between two thick low velocity layers will give arrivals having a higher than normal apparent velocity. Several cases are cited in support of this claim. No records are shown, however, that illustrate this effect nor is there any specific account of how the apparent velocity is associated with the bed in question.

In addition to the velocities of various specific stratigraphic columns throughout Spain, the maximum range of velocity for each type of strata within each of the major geologic periods and epochs is listed. The generally accepted notion that of two apparently similar strata the older will give the higher velocity is confirmed. It would be interesting to learn more about the system of computation used by Lopez de Azcona, especially how he correlated the various refraction events on his time-distance curves with the sequence of subsurface strata.

H. H. FROST
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"Geological Imagination in the interpretation of Geophysical Data," by R. Clare Coffin, *Quarterly of the Colorado School of Mines*, Vol. 45, No. 4A, pp. 11–40, October 1949.

This article, published a year ago, has escaped this reviewer's notice until now. The content is factual enough, the ideas stimulating , and style sufficiently pleasant to warrant a tardy review. The theme of the article has often been repeated. It may be greatly paraphrased as a reminder that geo-

physical data is a reflection of geological conditions, that the data's inapplicability is the result of inabilities in interpretation, and that interpretational powers need to be augmented. The theme is developed by means of examples in interpretation. Two seismic sections are presented first, each with and without the addition of geologic interpretation. The sections are complex and the demands on the resourcefulness of the geologist are apparent when the geology is added.

The gravity data illustrate the range of interpretational possibilities offered by both residual and regional data. The use of accessory magnetic data in resolving ambiguous gravitational data is interesting. Two local gravity features are several miles apart and seemingly arise from density contrasts at 3–4,000 feet. The southern feature also has a counterpart in a local magnetic anomaly and " . . . speculation would suggest that the pre-Cambrian was much deeper" in the north. "Exploration has proved the existence of structures at both locations and the pre-Cambrian . . . 3,500 feet deeper" in the north.

The theme becomes slightly distorted into a defense for the potential methods, quite naturally so as these methods permit greater latitude in interpretation than seismic data. But these aspects should not condemn the methods. They should challenge geophysicists and geologists alike to a greater understanding of potential data by dint of greater ability and imagination on their part.

NELSON C. STEENLAND

PUBLICATIONS RECEIVED

Listed below are all publications received at the business office of the society on subscription and through free exchange for *Geophysics* since publication of the last issue. Periodicals and separates indicated by the asterisk (*) have been forwarded to the Standing Committee on Reviews, and will be placed in the permanent depository of the society at the University of Tulsa Library. These publications are available for loan to members of the society on application to the business manager. Other publications will be held for a short time at the business office. Disposition of books listed is by direction of the Standing Committee on Reviews.

Periodicals

American Journal of Science, Vol. 248, Nos. 9, 10 and 11 (Sept.–Nov., 1950)
**Abhandlungen der Geologischen Landesanstalt* (Berlin), 211–219
**Annales de Geophysique*, Vol. 6, No. 3 (July–Sept. 1950)
**Annali di Geofisica*, Vol. 3, Nos. 2 & 3 (April & July 1950)
**Archiv fur Lagerstattenforschung*, Nos. 79 & 80
**Boletin de la Asociacion Mexicana de Geologos Petroleros*, Vol. 2, Nos. 5 & 6 (May & June 1950)
Bulletin of the American Association of Petroleum Geologists, Vol. 34, Nos. 9 & 10 (Sept. & Oct. 1950)
**Bulletin of the Hungarian Geological Society*, Vol. 79, No. 9–12; Vol. 80, No. 7–9
**Bulletin of the Seismological Society of America*, Vol. 40, No. 3 (July 1950)
**Articles on Geophysics in Current Russian Periodicals*, Lists 27 and 28 (April & Oct. 1950)
Economic Geology, Vol. 45, Nos. 6 & 7 (Sept.–Nov. 1950)
**Erdol und Kohle*, Vol. 3, Nos. 8 & 9 (Aug. & Sept. 1950)
**Geofisica Pura e Applicata*, Vol. 16, No. 3–4 (April–June 1950)
**Geofysiske Publikasjoner*, Vol. 17, Nos. 1–4 (1947–1949)
Institute of Petroleum Review, Vol. 4, No. 44 (Aug. 1950)
Instruments, Vol. 23, Nos. 9 & 10 (Sept. & Oct. 1950)
Journal of Applied Physics, Vol. 21, Nos. 9 & 10 (Sept. & Oct. 1950)
**Journal of the Chinese Geophysical Society*, Vol. 2, No. 1 (June 1950)
Journal of Geophysical Research, Vol. 55, No. 3 (Sept. 1950)
Journal of the Institute of Petroleum, Vol. 36, No. 319 (July 1950)
LEA, No. 12 (February 1950)
Nafta, Vol. 6, Nos. 7 & 8 (July & Aug. 1950)
**Nuclear Science Abstracts*, Vol. 4, Nos. 16–20 (Aug. 30 through Oct. 30, 1950)
Review of Scientific Instruments, Vol. 21, Nos. 8–10 (Aug.–Oct. 1950)
**Science Reports of the Tohoku University*, Vol. 1, Nos. 1 & 2 (Feb. & Nov. 1949); Vol. 2, No. 1 (Mar. 1950)
**Technical Data Digest*, Vol. 15, Nos. 4–11 (Apr.–Nov. 1950)
**Tellus*, Vol. 2, No. 2 (May 1950)

CONTRIBUTORS

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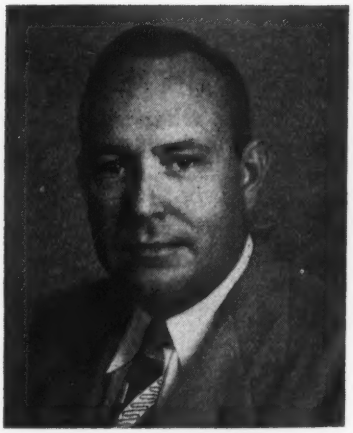
THOMAS B. BUFORD received his B.S. degree in geology from Louisiana State University in 1949. He began work for the U. S. Geological Survey as a geologic aid in 1948 and continued with that agency after receiving his degree.

NEAL CLAYTON was born August 23, 1913 in Ripley, Mississippi. He received an A.B. in Physics from Mississippi College in 1934. After a year of teaching, he enrolled at Louisiana State University, receiving the M.S. degree in 1937 while holding a teaching fellowship for two years.

He began work on a seismic crew for the Humble Oil and Refining Company in the summer of 1936 and after graduation worked on seismic crews in the States and in Eastern Venezuela. Later he was employed as computer, observer, and party chief by Seismic Explorations, Inc., the Magnolia Petroleum Company, and the North American Geophysical Company. From 1941 to 1943 he was an Associate Physicist with the Naval Ordnance Laboratory in Washington, D. C.

He joined the Republic Exploration Company in February, 1946, and at present he is supervisor of surface shooting for that company. He is a member of Phi Kappa Phi, Society of Exploration Geophysicists, American Association of Petroleum Geologists, and the Tulsa Geophysical and Geological Societies.



NEAL CLAYTON

G. D. GARLAND graduated from the University of Toronto in 1947 with the degree of B.A.Sc. in the Geophysics Option of Engineering Physics. He received the degree M.A. from the same University in 1948, doing his graduate research on gravity anomalies in the Canadian Shield. From 1948 to 1949 he was a Fellow in Geophysics at St. Louis University, and is at present working for his doctorate through that University. Since 1949 he has been lecturer in Geophysics at the University of Toronto. Mr. Garland has worked with the Dominion Observatory, Ottawa, for a number of seasons, on gravity and magnetic surveys in various parts of Canada. His particular interest is in the interpretation of potential field anomalies.

He is a member of the American Geophysical Union and the Association of Professional Engineers of Ontario, an associate member of the St. Louis Chapter of the Society of the Sigma Xi, and a student member of the Society of Exploration Geophysicists.

G. D. GARLAND

J. GOGUEL

J. GOGUEL graduated from Ecole Polytechnique and from Ecole Nationale Superieure des Mines de Paris. He belongs to the French Geological Survey, of which he has been assistant director since 1931. He has made very important geological studies in the Alps, particularly with respect to tectonics, and obtained in this connection a Doctor's degree in 1937. Has studied the application of mechanics to the investigation of tectonic movements. Since 1941, he has been assistant director of the Bureau of Geological and Geophysical Research, where he is personally in charge of the geophysical section.

He is professor at the Ecole Nationale Superieure des Mines.

In addition, he is professor at the Ecole des Ponts et Chaussees (State Highway Engineers). In this connection he has given a great deal of his time and attention to the geological and geophysical investigations of dam sites.

PAUL H. JONES

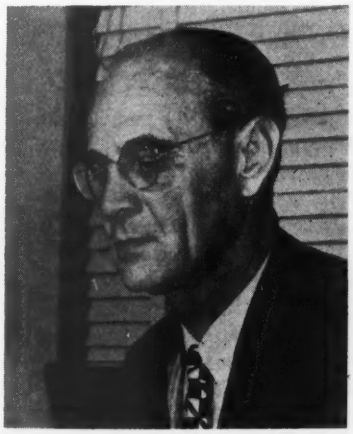
PAUL H. JONES received his B.S. degree in geology at Michigan State College in 1940 and his M.S. degree in geology at Louisiana State University in 1950. He was employed by the Halliburton Oil Well Cementing Company, Electrical Well Logging Department at Houston, Texas, in 1941 and served the company for one year. Early in 1942 he accepted an appointment as Junior Geologist, U. S. Geological Survey, Ground Water Branch, Louisiana District, and has worked for the Survey in Louisiana since that time, except for a one-month tour of duty in Chile, South America, in March 1950.

V. S. TUMAN was born in Kermanshah, Iran, in May 1923. In 1942 he went to Abadan Technical School and then in the summer of 1944 he was selected to go to England to study physics at Birmingham University. He graduated with honors from Birmingham University in May 1948 receiving a B.S. in physics. He was then sent to the Imperial College London University to study geophysics and was awarded the Diploma of the Imperial College (D.I.C.).

V. S. TUMAN

C. N. VALERIUS was born in Hoisington, Kansas, on December 9, 1904. He received his B.S. in geology from the Missouri School of Mines in 1925. From 1925 to 1927 he was engaged as a surface geologist for the Twin State Oil Company in Oklahoma. From 1927 to 1929 he was with Phillips Petroleum Company and later with Amerada Petroleum Corporation as a surface and sub-surface geologist in the Trans-Pecos area. From 1929 to 1935 he was manager and geologist for the M. M. Valerius Royalty Corporation operating in Kansas and Oklahoma. In 1935 he was employed by Barnsdall Oil Company and later served as District Exploration Manager at Shreveport and Wichita Falls. Since 1949 he has been maintaining a consulting geological office at Shreveport. He is a member of the American Association of Petroleum Geologists, American Association for the Advancement of Science, American Geophysical Union, and the Shreveport Geological Society.

C. N. VALERIUS



STEFAN VON CROY

STEFAN VON CROY entered the Technical University of Graz, Austria, in 1919 to study chemistry. In 1920 he transferred to the School of Mines at Leoben, Austria, and took up electrical engineering, majoring in metallurgical engineering. He finished school in 1924 and at that time entered the employ of Piepmeyer & Company, a mining concern at Kassel, Germany; between 1924 and 1926 he worked in various parts of Europe for the Elbof Exploration Company, which was a geophysical subsidiary of this concern. He was sent to the United States as a representative of this company and was instrumental in forming their subsidiary in the Western Hemisphere. As their technical advisor he worked in various parts of the United States and Mexico between 1926 and 1930, and then returned to Europe. Shortly afterward he went to South America for the same company.

In 1932 he returned to the United States and entered the employ of McCollum Exploration Company in Houston, Texas. In 1935 he took a position as geophysical supervisor for Barnsdall Oil Company and was promoted in 1940 to the position of chief geophysicist. He worked in this capacity until 1950, at which time the merger of Barnsdall Oil Company with Sunray Oil Corporation became effective. At the present time he is a geophysicist for Sunray Oil Corporation in their headquarters office in Tulsa.

In addition, references are cited to earlier issues for the biographies of: Milton Dobrin, Vol. XV, No. 4 (October, 1950); Thomas A. Elkins, Vol. VII, No. 1 (January, 1942); B. G. Swan, Vol. VII, No. 4 (October, 1942).

SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the president within thirty days. Names of the references appear in parentheses after the name of each nominee.

ACTIVE

William Marsden Anderson (R. L. Lay, A. A. Hunzicker, R. N. Harding)
Randell Bruce Carter (E. A. Eckhardt, C. H. Dresbach, J. C. Heggblom)
George Frederick Coote (C. A. Heiland, Carl Chapman, C. N. Hurry)
David Smith Godshalk (B. G. Swan, L. E. Whitehead, J. M. Crawford)
Floyd H. Morris (A. J. Hintze, W. H. Courtier, R. P. Clark)
Joseph Brooks Parkhill (R. B. Ross, J. M. Kilborn, R. G. Reiser)

TRANSFER TO ACTIVE

Orven Harry Armstrong (P. E. Nash, J. C. Menefee, D. R. Dobyns)
George Robert Belt (W. C. Lamb, Frank Mortlock, Ralph Ross)
Walter C. Bonebrake (O. C. Clifford, Jr., C. H. Hightower, R. F. Van Cleave)
Everett Lawyer Campbell (P. L. Farren, W. H. Amis, Jr., John A. Gillin)
David Wood Cochrane (R. W. Mossman, C. E. McClure, H. M. Thralls)
Donald Crary (R. F. Bennett, T. I. Harkins, F. A. Smith)
Charles J. Deegan (E. A. Eckhardt, G. H. Westby, H. Wayne Hoylman)
Laurence Newton Dexter (E. L. DeLoach, R. F. Van Cleave, M. S. Hathaway)
Kenneth Edgard Gibbs (Frank Ittner, T. E. Dennis, J. E. Stones)
Owen Bruce Hall (Opie Dimmick, Dave Weichert, Neal Clayton)
Paul Van Hodge (C. H. Green, H. B. Peacock, N. W. Mann)
Earl William Johnson (R. M. Bradley, Vincent Miller, R. H. Tucker)
Jack Charles Kern, Jr. (G. J. Long, Sidon Harris, C. J. Donnally)
Frank Marion Mitcham (A. A. Hunzicker, J. P. Garner, Stefan Von Croy)
Spencer Raphael Normand (James L. Morris, J. B. Lovejoy, R. W. Dudley)
Benjamin Franklin Owings, Jr. (Lorenz Shock, E. D. Alcock, M. P. Jones)
Arleigh Ray Patterson (Wayne H. Denning, Edward G. Schempf, Norman J. Christie)
James Wesley Richardson (F. W. Borman, W. T. Born, Andrew Gilmour)
Lewis V. Roos (Roy L. Lay, A. A. Hunzicker, C. R. Wallace)
Calbert Byron Selmser (John H. Hodgson, Arthur A. Brant, C. S. Johnson)
Grover C. Shivers, Jr. (Sidon Harris, R. H. Dana, Booth B. Strange)
Almon Horton Smith, Jr. (Kenneth E. Burg, F. J. Agnich, V. W. Teufel)
James Allen Standridge (Sidon Harris, Paul Ledyard, R. H. Dana)
Fred L. Travis, Jr. (O. C. Clifford, Jr., C. H. Hightower, A. E. McKay)
Charles Andrew Weeth (Robert S. Duty, Jr., J. A. Brooks, Jr., M. M. Slotnick)
Maurice Dennick Wickerham (E. A. Eckhardt, L. J. Peters, J. E. McGee)
Albert Lee Wilkinson (R. F. Kittredge, W. Lee Moore, D. B. Winfrey)

ASSOCIATE

George Alonzo Bell, Jr. (S. K. Van Steenbergh, Kirby J. Warren, James F. Johnson)
Ansel Q. Berglund (E. D. Alcock, K. H. Waters, B. J. Sorrells)
James Schnack Bigelow (H. R. Thornburgh, Jesse Parker, J. Walker Locke)

Wesley Edward Bird, Jr. (H. R. Prescott, B. G. Swan, C. K. Shepherd)
John Norman Botkin (Sidon Harris, R. H. Dana, Walter D. Baird)
James Andrew Callahan (J. B. Macelwane, M. C. Kelsey, J. F. Rollins)
Dean M. Denton, Jr. (T. L. Kunkel, J. S. Welboan, Jr., R. L. Lay)
Miss Joe Doss (George D. Mitchell, Jr., R. K. Carter, Hart Brown)
Ned Edward Duval, Jr. (Ralph Loring, F. A. Van Melle, F. Goldstone)
Ray Estell Faudry (S. B. Stewart, Charles C. Sellers, R. F. Bennett)
Marion Thomas Friday (O. C. Clifford, Jr., C. H. Hightower, A. E. McKay)
Oscar John Kastner, Jr. (W. O. Bazhaw, James R. New, C. D. Roemer)
Francis Richard Klima (Flint H. Agee, Edw. G. Schempf, L. K. Morris)
William Kopka (M. A. Boccalery, B. B. Strange, Thomas P. Maroney)
Sammy G. Manos (W. A. Meszaros, R. B. Ross, Robert C. Heron)
James Gerard Miller (R. L. Lay, W. L. Irwin, F. R. Coryn)
James Robert Pace (Kenneth E. Burg, Gordon D. Cloepfil, V. W. Teufel)
Robert Jay Purdy (C. M. Ross, F. W. Borman, Andrew Gilmour)
Lorne Herbert Reed (L. I. Brockway, R. J. Copeland, S. G. Pearson)
Glenn Robertson (F. Goldstone, R. D. Miller, T. S. Edrington)
Frederick Eugene Schultz (A. G. Starr, J. W. Bolinger, S. A. Teasley)
Arnold MacLean Tibbetts (Wayne Denning, Nash H. Miller, John C. Hoffman)
Pieter Vermeulen (Oscar Weiss, John Berning, B. C. Alberts)
Walter A. Ver Wiebe (Paul Weaver, L. L. Nettleton, W. E. Pratt)
William M. Walkup (C. H. Green, K. E. Burg, A. E. Storm)
Raymond William Western (A. W. Speckels, J. M. Van Tuyl, W. S. Levings)
Ocie Geron Williams (Lee B. Park, Hugh McCain, Jr., C. H. Hightower)

TRANSFER TO ASSOCIATE

Graham Clifford Alvey (J. H. Hodgson, P. P. Gaby)
Charles Andrew Arsenault (S. B. Stewart, Donald C. Crary, R. F. Bennett)
Kevin Michael Barry (J. B. Macelwane, Florence Robertson, W. A. Meszaros)
Robert Hugh Bixby (H. R. Prescott, E. L. Mount, A. I. Levorsen)
Leonard Stanier Collett (A. A. Brant, J. H. Hodgson, E. A. Hodgson)
Robert Clyde Cowles (F. Goldstone, Florence Robertson, Victor J. Blum)
Howard Wesley Green (F. J. Agnich, Earl Thomas, H. E. Stommel)
Robert Joseph Koenig (L. G. Ellis, W. E. Hollingsworth, L. W. Konz)
Ward Townsend Langstroth (R. D. Holland, F. R. Coryn, Roy L. Lay)
Darragh Hawthorne McFadden, Jr. (L. G. Ellis, W. E. Hollingsworth, Leo W. Konz)
Calvin Floyd Neill (R. M. Bradley, W. T. Lea, R. E. Butler)
Kenneth Lewis Parker (J. F. Freel, R. B. Briggs, C. H. Broussard)
John Henry Ratcliffe (E. W. Westrick, James A. Affleck, T. J. O'Donnell)
George Shor, Jr. (F. F. Reynolds, R. R. Rosenkrans, John D. Marr)
Robert James Uffen (J. H. Hodgson, Howard McCurry, Weston Bourret)
Leonard A. Woker (V. J. Blum, M. L. Benke, W. H. Gibson)

REINSTATEMENT TO ACTIVE

Gwendolyn Peabody Lockett

RESIGNATION

Thomas J. Countis, Student
Donald R. Martin, Student
David S. Muzzey, Jr., Active
Douglas M. Pogue, Student
Beverly W. Robinson, Student
Saul Stimler, Associate
Gertrude R. Whiting, Associate

ADDITIONAL APPLICATIONS APPROVED FOR PUBLICATION

ACTIVE

Fritz Rudolf Beer (Nat Prade, Peter Stoutjesdyk, Harry Pearson)
William Wallace Bingham (Leo J. Peters, Ralph B. Ross)
Paul Blevins (Fisher Reynolds, John D. Marr, H. C. Smith)
Richard McDonald Davis (Paul L. Lyons, John R. Hill, Marvin Romberg)
T. F. Dupont, Jr. (F. F. Reynolds, John D. Marr, H. H. Happel)
Paul Miller Early (Frank Searcy, R. F. Hughes, B. G. Swan)
James Howard Frasher (K. H. Waters, E. D. Alcock, E. L. Campbell)
William Ridgely Hadaway (Roy L. Lay, W. L. Irwin, V. E. Briard)
Burton H. Hinton (James C. Menefee, E. S. Sherar, R. P. Warren)
Berend Jan Hoffman (Nat Prade, P. S. Stoutjesdyk, Harry Pearson)
Herman Logan Hoover (Roy L. Lay, B. H. Treybig, Jr., C. R. Wallace)
Wayne Welwyn Jameson (E. L. Mount, George A. Grimm, R. R. Rosenkrans)
Robert Parker Kennedy (B. H. Treybig, Jr., C. C. Zimmerman, H. W. McDonold)
Forrest Frank Lambrecht (L. A. Scholl, Jr., Roy L. Lay, A. A. Hunzicker)
Patrick Elvin Mackey (F. F. Reynolds, John D. Marr, R. R. Rosenkrans)
Alton McClung (Roy L. Lay, V. E. Child, A. A. Hunzicker)
James Bruce Meadours (A. G. Nance, Joe B. Barbixch, K. G. McCann)
Emmet Dean Riggs (O. C. Clifford, Jr., J. P. Woods, Charles H. Hightower)
Duncan Burdette Robinson (Herbert Hoover, Jr., E. A. Pielemeier, E. G. Schempf)
Harold A. Sears (Eugene Frowe, R. F. Bennett, J. H. Crowell)
Francis Sewell (M. L. Benke, W. H. Gibson, J. B. Nichols)
Gerard H. F. Snyders (A. van Weelden, V. P. Ulrich, P. S. Stoutjesdyk)
Paul W. Stokely (R. R. Rosenkrans, John D. Marr, F. F. Reynolds)
Rayman Sturdevant (H. R. Thornburgh, J. C. Waterman, K. S. Cohick)
Lloyd Owen Thomas (Opie Dimmick, W. B. Sibley, W. G. Green)
Paul Marton Thompson (Roy L. Lay, C. R. Wallace, B. H. Treybig, Jr.)
Fernando Vila (Rodolfo Martin, Andres Rozlosnik)
Frederick Bradley Wallis (Roy L. Lay, L. A. Scholl, Jr., C. S. Johnson)
Horatio Coburn Weston (L. G. Ellis, W. E. Hollingsworth, J. H. Sawyer)
Ronald E. Wright (Earle W. Johnson, Thomas O. Hall, J. S. Spencer)
Robert Otis Wynn (Robert H. Ray, Eugene W. Frowe, Sam Rogers)

TRANSFER TO ACTIVE

Wallace Wayne Adams (W. C. Merritt, P. J. Jacobsen, Jr., W. E. Franks)
James Harrison Bush (Edwin L. Fetzer, Jerome R. Burns, Ira Mayfield)
Louis Castelli (Russel B. Cornell, George W. Isensee, Harold James Kidder)
Hendrik Paulus Coster (E. J. P. van der Linden, A. A. Fitch, C. B. Twardowski)
Roy Floyd (O. C. Clifford, Jr., C. H. Hightower, E. L. DeLoach)
Frans Hardin Hammons (K. C. Thompson, J. W. Fishback, C. J. Long)
Claude Daniel Pentecost (Homer C. Moore, J. P. Garner, H. B. Peacock)
Grant M. Roberts (Dean Walling, Dupree McGrady, V. E. Prestine)
Jack Robertshaw (J. M. Bruckshaw, R. Glossop, H. Q. Golder)
Carlton Thomas Spalding (Sam D. Rogers, J. B. Nichols, Robert H. Ray)
Joe Richard Wier (John W. Lipscomb)
Sulhi Yüngül (Beno Gutenberg, G. W. Potapenko, P. Dehlinger)

ASSOCIATE

Harold Truett Austin (F. Goldstone, L. K. Mower, R. C. Hilton)
Karl Eugene Baer (A. A. Hunzicker, W. L. Irwin, V. E. Child)

Lawrence Robert Baxendale (J. W. Rhymes, H. E. Shell, T. E. Dennis)
L. R. Book, Jr. (M. L. Benke, Wm. H. Gibson, J. B. Nichols)
Robert Kay Bradley (W. L. Irwin, T. L. Kunkel, V. E. Child)
Lonnie Lewis Brantley, Jr. (Harris Cox, C. J. Donnally, B. B. Strange)
Gerald Allison Cooley (Samuel A. Spencer, Ronald E. Beck, H. J. Owen)
John Alfred Crager (Ewin D. Gaby, George Augustat, W. F. Albers)
Ernest William Creasey (H. J. Kidder, A. J. Oden, Harris Cox)
J. Lee Davis (Clark Bissett, Guy M. Ratliff, Leland Snow)
Dirk Dekker (John Carr, H. C. Maliphant, J. J. Augusteijn)
William Duchscherer, Jr. (V. Gabriel, Sidon Harris, A. E. McKay)
Donald Wayne Fleming (R. M. Bradley, W. T. Lea, R. E. Butler)
James Rolf Gaebe (John M. Crawford, Loren Whitehead, B. G. Swan)
Steward Paul Gagnon (John L. Bible, K. C. Thompson, J. W. Fishback)
Jack Hos George (Byron K. Johnson, A. B. Hamil, G. M. Mace, Jr.)
Douglas Dale Goddard (T. O. Hall, Chester Sappington, I. M. Griffin, Jr.)
Dean Harlow Hammond (Roy L. Lay, C. R. Wallace, Vernon E. Briard)
Warren Gamaliel Hicks (H. H. Frost, M. B. Dobrin, D. H. Clewell)
Walter L. Hurt (F. F. Reynolds, John D. Marr, Hugh Porter, Jr.)
Anthony Mark Knouse (Roy L. Lay, W. H. Gibson, M. L. Benke)
John D. Lahmeyer (J. A. Sharpe, W. H. Courtier, W. T. Born)
William David LeBay (Erik Thomsen, D. W. Ratliff, G. V. Dunn)
Francis Martin Lehner (H. R. Thornburgh, J. C. Waterman, K. S. Cohick)
Everett M. May (R. C. Sweet, E. V. McCollum, Craig Ferris)
Clarence O'Bannon Morrison (E. D. Gaby, George Augustat, A. G. Harvey)
Eufrasio Isidro Orellana (Rodolfo Martin)
John Butler Pitts (Roy Bennett, W. B. Lee, J. W. Fishback)
Frederick William Popp, Jr. (Ray W. Walling, K. C. Thompson, J. W. Fishback)
Gaston Douglas Ramzinsky (Hugh Porter, Jr., Edward F. Zagst, H. V. Crowder)
James Clifford Rees (O. Koefoed, J. McG. Bruckshaw, A. van Weelden)
Carl Fredrick Romney (Roland F. Beers, Perry Byerly, William B. Heroy)
Henry Bernhard Sawatzky (Guy M. Ratliff, Herbert F. Dodson)
Francis Augustus Seamans (A. A. Hunzicker, T. L. Kunkel, J. S. Welboan, Jr.)
William Oliver Smith (J. D. Marr, B. H. Hinton, H. L. Gaither)
Juan Francisco Tognon (Rodolfo Martin)
David Edwin Willis (C. C. Zimmerman, H. W. McDonnold, E. C. Martin)

TRANSFER TO ASSOCIATE

Vernon Kalen Anderson (A. R. Kassander, C. J. Roy, K. M. Hussey)
Victor Francis Capatch (B. F. Howell, Lloyal O. Bacon, Sylvain K. Pirson)
Warren E. Daniels (James B. Macelwan, S.J., Victor J. Blum, S.J., Florence Robertson)
John S. Dowsett (A. A. Brant, John Hodgson)
John Boyd Etnyre (L. O. Seaman, J. J. Rupnik, R. D. Schmidt)
Hugh Evans, Jr. (H. E. Stommel, John M. Crawford, B. G. Swan)
George David Garland (John H. Hodgson, James B. Macelwane, S.J., Arthur A. Brant)
Arthur James Gude III (H. E. Stommel, R. C. Holmer, C. A. Heiland)
Thomas Narcisse Hanrahan (James Affleck, Paul O. Fink, V. J. Blum, S.J.)
Marvin Ray Hewitt (Howard Itten, R. C. Holmer, Harrison Stommel)
William Neal Hostetter (H. E. Stommel, Ralph Holmer)
Anthony William Hummel (V. J. Blum, S.J.)
Chet Houston Jameson, Jr. (T. A. Manhart, H. M. Thralls, W. E. Pugh)
Harold Meadow (James T. Wilson, Perry Byerly)
Leland Eugene Moore (V. L. Jones)

Edward Andrew Morrison (John C. Hollister, H. E. Stommel, R. C. Holmer)
Bobby Glynn Preston (J. G. Jackson, C. E. McClure, H. M. Thralls)
Charles Albert Schad (V. L. Jones, R. Mathieson, Colin Campbell)
Robert Charles Schwab (F. M. Van Tuyl, J. Harlan Johnson, Opie Dimmick)
Harold Oscar Seigel (Arthur Brant, J. T. Wilson, Lachland Gilchrist)
Gerald Francis Slattery (James B. Macelwane, S.J., H. R. Thornburg, J. C. Waterman)
Russell William Stephenson (H. B. Peacock, C. H. Green, K. C. Van Orden)
William Hilliard Throop (H. E. Stommel, R. C. Holmer, J. P. Woods)
Stanley Harry Ward (A. A. Brant, J. Hodgson)
Andrew Wolikowski (John Hollister, G. T. Merideth, C. G. Faubion)

REINSTATEMENT TO ACTIVE

John W. Daly

RESIGNATION

J. W. Austin, Student
A. E. Brayton, Associate
Nathan C. Davies, Active
Hugh W. Hardy, Associate (Military leave)
James S. Latenser, Associate
Charles Lee Moore, Associate
Carel Otte, Jr., Student
Richard S. Rector, Associate
William G. Smiley, Jr. (Deceased)
Max Steineke, Active
C. J. Thomsen, Associate
W. W. Wetzel, Active
Vincent Emanuel, Active

REPORT OF SPECIAL CONSTITUTION COMMITTEE

Mr. George E. Wagoner
The Carter Oil Company
Drawer 1739
Shreveport, La.

Dear Mr. Wagoner:

As requested in your letter of June 16, 1950 appointing me as chairman of the Special Constitution and By-Laws Committee of the Society of Exploration Geophysicists, I appointed the following as members of that Committee: Messrs. Henry Cortes, Andrew Gilmour, Cecil Green, J. J. Jakosky, and L. L. Nettleton. We have considered the problems raised by the Council and make the following recommendations for changes in the By-Laws of the S.E.G.:

The Special Committees would be set up as Standing Committees by amending the By-Laws Article X, Section 1 by deleting the word "and" preceding the words "(g) Standing Committee on Student Membership," and adding, following those words, the words "(h) Standing Committee on Distinguished Lectures; (i) Standing Committee on Radio Facilities; (j) Standing Committee on Special Reviews; (k) Standing Committee on Public Relations and Publicity; and (l) Standing Committee on Annual Review of Geophysical Activity."

The solution to the second problem posed by the Council would be to amend By-Laws Article IX, Finances of Local Sections, Section 1 by deleting the words "will pay" following the words "The Society" and substituting therefor the words "may, at the discretion of the Council, pay any portion of."

In Article VII, Section 6. Delete the words "personally supervise the counting of" and substitute therefor "appoint tellers to count."

Respectfully submitted,
W. M. Rust, Jr.

October 16, 1950

THE AMERICAN GEOLOGICAL INSTITUTE

It probably is not news to many of our members that the S.E.G. is one of the thirteen original member organizations of the A.G.I. but the operation and purpose and the possibilities of service which the Institute may render to the geological profession are not well understood. The series of Distinguished Lectures early this year by Dr. David Delo, executive director of the Institute, did much to point out the concepts under which A.G.I. was organized and what it hopes to accomplish. Much remains to be done to make the A.G.I. better known to the members of the constituent societies. As an aid in keeping our membership informed, we plan to have each number of *Geophysics* carry a page of news about A.G.I. activities.

The regular annual meeting of the directors of A.G.I. was held in Washington on November 19th. The S.E.G. was represented by L. L. Nettleton, whose term as director expired with that meeting. (The directors who now represent the society are Henry C. Cortes—tenure expires 1951—and Andrew Gilmour—tenure expires 1952.) Approximately 25 officers and directors were present, with all the member societies represented by one or two directors. The meeting occupied the entire day so only a few points of special interest can be mentioned here.

A great deal of discussion was given to the possibility of the A.G.I. undertaking the publication of a geological abstract journal which would be broad enough in its scope to serve the entire profession. There are four current abstract journals: Bibliography and Index of North American Geology, published by the U.S.G.S.; Geophysical Abstracts, published by the U.S.G.S.; Bibliography and Index of Geology Exclusive of North America, published by the G.S.A., and Annotated Bibliography of Economic Geology, published by Economic Geology Publishing Co. From figures on the costs of these abstract journals, it is estimated that a single journal, serving the same purpose, would cost about $50,000 per year to produce. The discussions were of an exploratory nature and much remains to be worked out before it can be decided definitely whether or not an abstract journal can be undertaken by the Institute. As a project which would serve the entire profession, it is one which is well within the province of the Institute, as it would be of service to all geologists.

The problem of making geology and geologists better known to the lay public was discussed. It may be remembered that publicity for geologists was advocated by Carey Croneis in 1943 at Ft. Worth at the meeting from which the A.G.I. finally developed (Bull. A.A.P.G., Vol. 27, No. 7 (July 1943), pp. 1001–1009). Dr. Delo considers the broad scale promotion of the function and usefulness of geology as fundamental to the continued existence of the A.G.I. Only as the service which geologists can render becomes widely known can they expect the support in interest and money which a strong A.G.I. will require.

The future financial support of the Institute is, of course, a problem of first importance to a new and growing organization. At present, the A.G.I. is supported largely by the National Research Council, the G.S.A. and the A.A.P.G. The support now promised will carry for about one more year. Other means of continued support are being actively considered by the finance committee, under the chairmanship of Roger Dennison. It is of interest to record that contributions have been made to the Institute, in amounts ranging from $100 to $200, by the Pittsburgh, Houston, Dallas, West Texas and Shreveport Geological Societies. It is hoped that, as the Institute proves its value by services rendered to the geological profession, means can be found by which the members of the profession will be willing and able to give it the support required for a healthy existence.

L. L. NETTLETON

ANNOUNCEMENT REGARDING ANNUAL MEMBERSHIP LIST

Members of the Society of Exploration Geophysicists are requested to examine the listing of their names in the membership list published in *Geophysics*, Vol. XV, No. 2 (April, 1950). Any inaccuracies in that listing must be reported to the business office of the society not later than February 1, 1951 to avoid repetition in the list to be published in April 1951 *Geophysics*.

PERSONAL ITEMS

KARL H. KUNDERT, for 7 years assistant chief geophysicist for the Barnsdall Oil Company, has joined the Ohio Oil Company as geophysicist for their Rocky Mountain division with headquarters in Sidney, Nebraska.

CHARLES H. DRESBACH has become Directeur General of Societe Nord-Africaine des Petroles, a subsidiary of Gulf Oil Company.

ELMER W. ELLSWORTH, assistant business manager of the American Association of Petroleum Geologists, has renewed his active membership in the S.E.G. Dr. Ellsworth became a member of the society in 1936.

JOSEPH H. SHARPE, vice president of Frost Geophysical Corporation, Tulsa, spoke at the October 12th meeting of the Oklahoma City Geological Society on the subject of aeromagnetometry as a primary reconnaissance tool.

J. R. MAXEY, formerly chief geophysicist for Deep Rock Oil Corporation, has entered the consulting business in Tulsa, specializing in review of seismic and geological prospects. Previous to going with Deep Rock, he had been connected with Humble Oil & Refining Co., Sohio Petroleum Co. and United Geophysical Co. He holds the degree of M.S. in Geology from the University of Oklahoma.

ALBERT W. MUSGRAVE has returned to the Colorado School of Mines on a fellowship provided by Magnolia Petroleum Co. to complete requirements for a D.Sc. in Geophysics.

JOHN DALY, former Honolulu Oil Corporation seismologist, has been named supervisor of the West Texas district for General Geophysical Company, and will make his headquarters in Midland.

JOHN C. PFLUEGER has returned to the campus of Lehigh University, Bethlehem, Pa., after working during the summer months of 1950 for Western Geophysical Company.

E. F. STRATTON, exploitation manager for Schlumberger Well Surveying Corp., has returned from Denver to the home office of the company at 1720 Esperson Building, Houston, Texas.

LT. COL. JACK N. NAHAS is now with the Decatur Signal Depot, Decatur, Ill.

P. M. MCNALLY has been promoted from party chief to district geophysicist for Phillips Petroleum Co., and is now located in the Permian Building, Midland, Texas.

F. REX WALLING, JR., party chief for Stanolind Oil & Gas Co., has transferred from Jayton to Spur, Texas.

MALVIN G. HOFFMAN has retired from government service, and has moved to 1002 Burch Street, Ardmore, Oklahoma. During World War II he was chief of the Petroleum Reserves Section in the Petroleum Administration for War. During the past four and one-half years he was in the Department of State as a specialist in international petroleum affairs.

U. J. CHAPUT, International Petroleum Co., Talara, Peru, has moved to 11 Duplex Crescent, Toronto, Canada.

C. G. WALTERS, formerly with the Geotechnical Corporations, now operates the Walters Drilling Company, Inc., at 2608A Inwood Road, Dallas 9, Texas.

C. B. FORBES, resident seismologist for United Geophysical Co., has been transferred from Calgary to Box 527, Riverton, Wyoming.

RAIFORD H. BURTON is now located at 1204 West Michigan Ave., Midland, Texas.

C. Y Fu announces the establishment of the Institute of Geophysics and Meteorology, Academia Sinica, Nanking, China. In a letter dated July 28, 1950, Dr. Fu advised that "as the new name of the Institute shows, the geophysical activity is expanding here." His letter was received November 15th.

F. L. Bishop announces the removal of his office from the National Bank of Tulsa Building to Suite 1408 Philtower Building, Tulsa, Oklahoma.

Robert F. Dundon has joined Aramco Overseas Company with offices at Via Sistina 131, Rome, Italy.

Jacques LeBlanc is now with Compagnie Generale de Geophysique at 50 Rue Fabert, Paris VII, France.

Lewis D. Strutzel, formerly with Superior Oil Co., Bahrein Island, Persian Gulf, is now with Caribbean Petroleum Co., Maracaibo, Venezuela.

H. H. Moody has resigned the position of party chief for Rayflex Exploration Company, and is now with Continental Oil Company, Ponca City, where he holds the position of supervisor.

Hal R. Adams has resigned as geophysical supervisor with the Geotechnical Corporation, and has joined the Sohio Petroleum Company as geophysicist in connection with their Canadian operations. His company address is 1822 Albert Street, Regina, Sask., Canada.

H. C. Petersen, Superintendent of Land and Exploration Dept. of Freeport Sulphur Company, has been transferred from New Orleans to 3100 Gulf Building, Houston.

Hugh P. Downey, formerly with McCollum Exploration Company, is now party chief for Weiss Geophysical Corp. of Canada, Greyhound Building, Calgary.

Wallace W. Adams has been transferred to the geological district office of the Creole Petroleum Corp. at Tia Juana, Estado Zulia, Venezuela.

Peter Dehlinger resigned from the Shell Oil Co., Inc. in September, 1948 in order to do graduate work in geophysics at the California Institute of Technology. He received the Ph.D. degree in geophysics in June, 1950 after two years as a graduate student and graduate assistant. Since July he has been on the staff of the Battelle Memorial Institute in Columbus, Ohio in the capacity of geophysicist.

L. Van der Harst has resigned from Seismograph Service Ltd., London, to accept the position of geologist with N. V. Nederlandse Pacific Petroleum Mij., Pakanbaroe, Sumatra, Indonesia.

J. H. Todd has become southern division exploration superintendent for the California Company. He succeeds L. I. Brown, who recently became assistant general manager of exploration.

Peter Dehlinger, formerly seismologist for Shell Oil Company, Inc., has accepted an appointment to the staff of Battelle Institute, where he will be engaged in research for the drilling industry.

Robert S. Dahlberg, Jr., Lead Research Man with Creole Petroleum Corporation in Caracas, Venezuela, has returned to the United States with the Philco Corporation to study microwave-relay problems.

Willis W. Hardy has moved up from chief geophysicist to assistant chief of the exploration division of Socony-Vacuum Oil Co., Inc. He joined the company in 1938 and held the former position for 1939 until this year.

Dean Walling has been elected executive vice president, and V. E. Prestine has been elected vice president and assistant manager of operations of the recently reorganized Western Geophysical Company of America.

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933 of GEOPHYSICS, published quarterly at Menasha, Wisconsin for January, 1951.

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County of Tulsa }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Colin C. Campbell, who, having been duly sworn according to law, deposes and says that he is the business manager of GEOPHYSICS, and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, Society of Exploration Geophysicists, Box 7248, Tulsa 18, Oklahoma; Editor, Richard A. Geyer, Box 2180, Houston 1, Texas; Managing Editor, Richard A. Geyer, Box 2180, Houston 1, Texas; Business Manager, Colin C. Campbell, Box 7248, Tulsa 18, Oklahoma.

2. That the owner is Society of Exploration Geophysicists, Box 7248, Tulsa 18, Oklahoma; President: George E. Wagoner, Box 1739, Shreveport, La.; Vice President: Sigmund Hammer, Box 2038, Pittsburgh 30, Pa.; Secretary-Treasurer: Francis F. Campbell, Box 2040, Tulsa 2, Oklahoma; Past President: Andrew Gilmour, Box 2040, Tulsa 2, Oklahoma.

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5. That the average number of copies of each issue of this publication sold or distributed through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is ————————. (This information is required from daily publications only.)

COLIN C. CAMPBELL (Signed)

Sworn to and subscribed before me this 2nd day of October, 1950.
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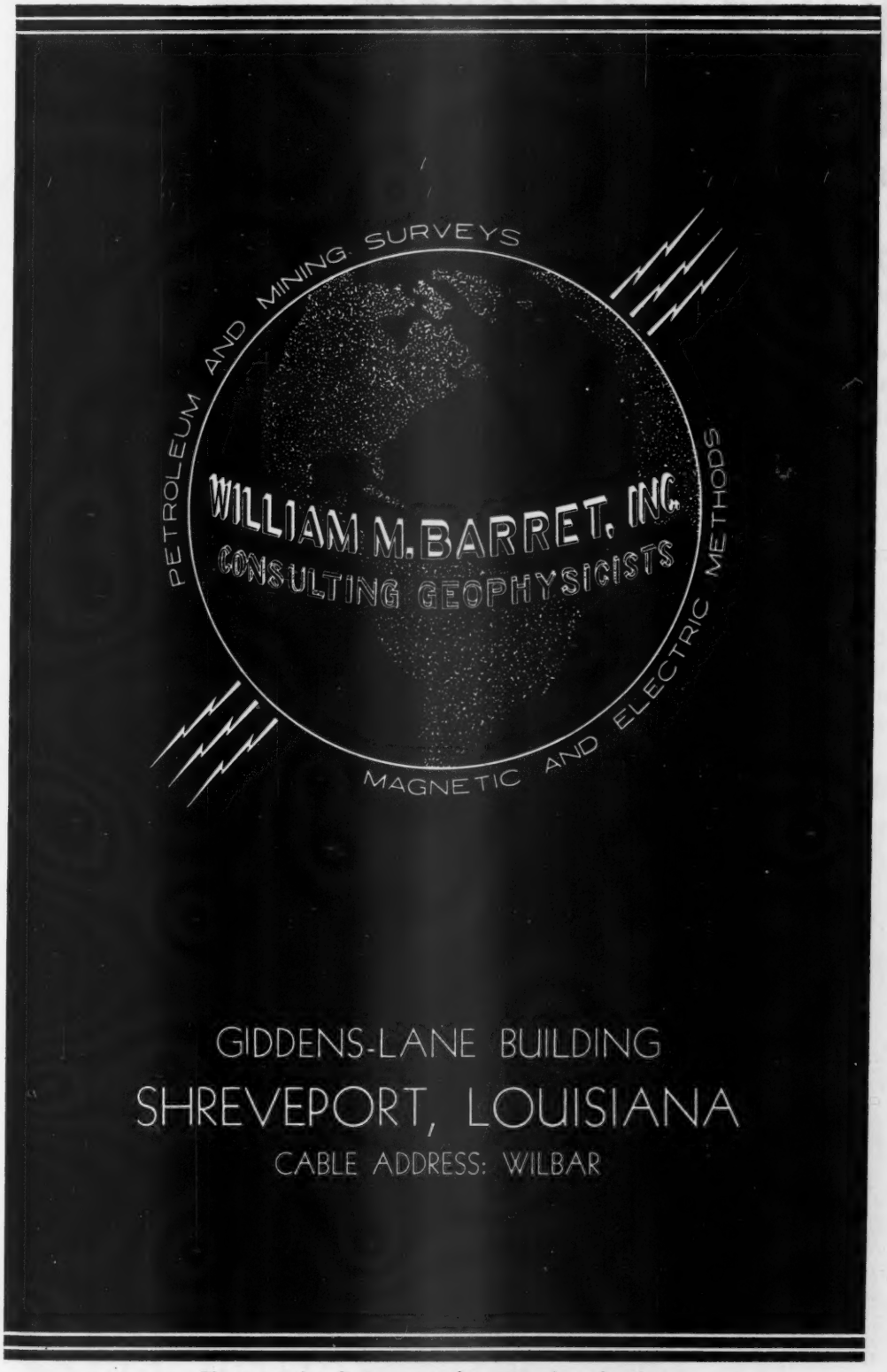
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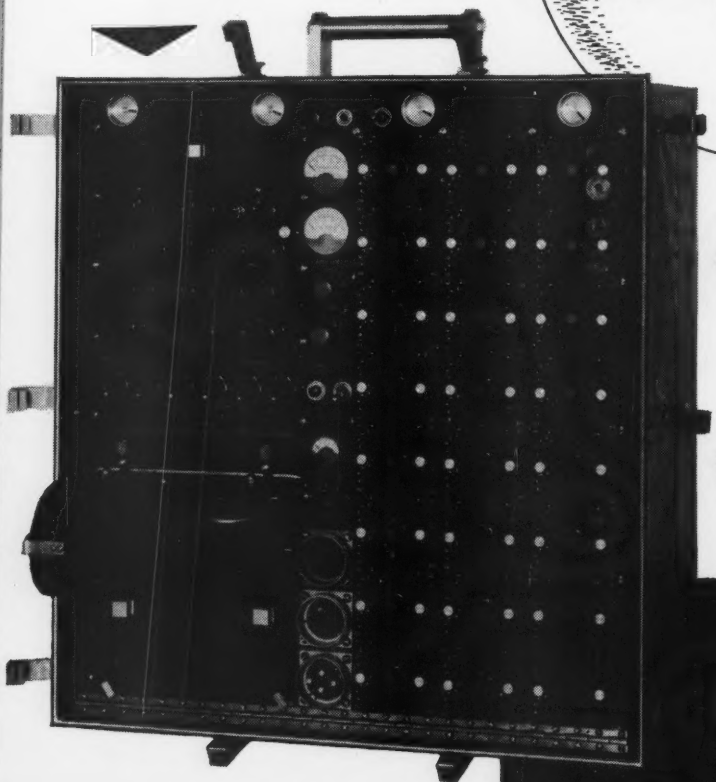

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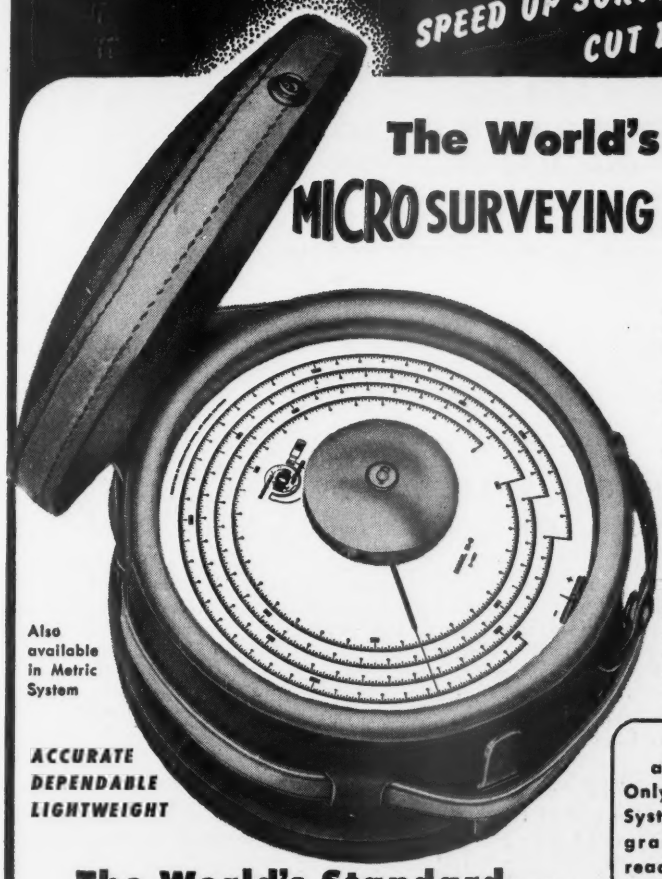

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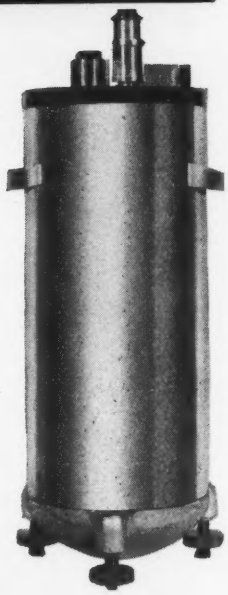

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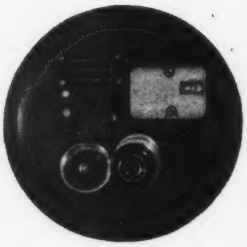

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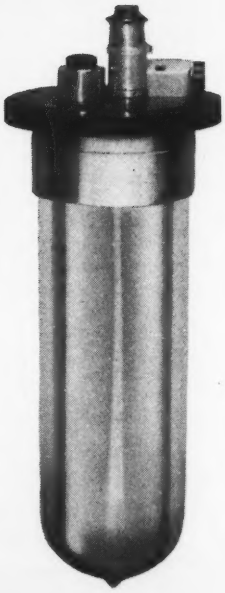

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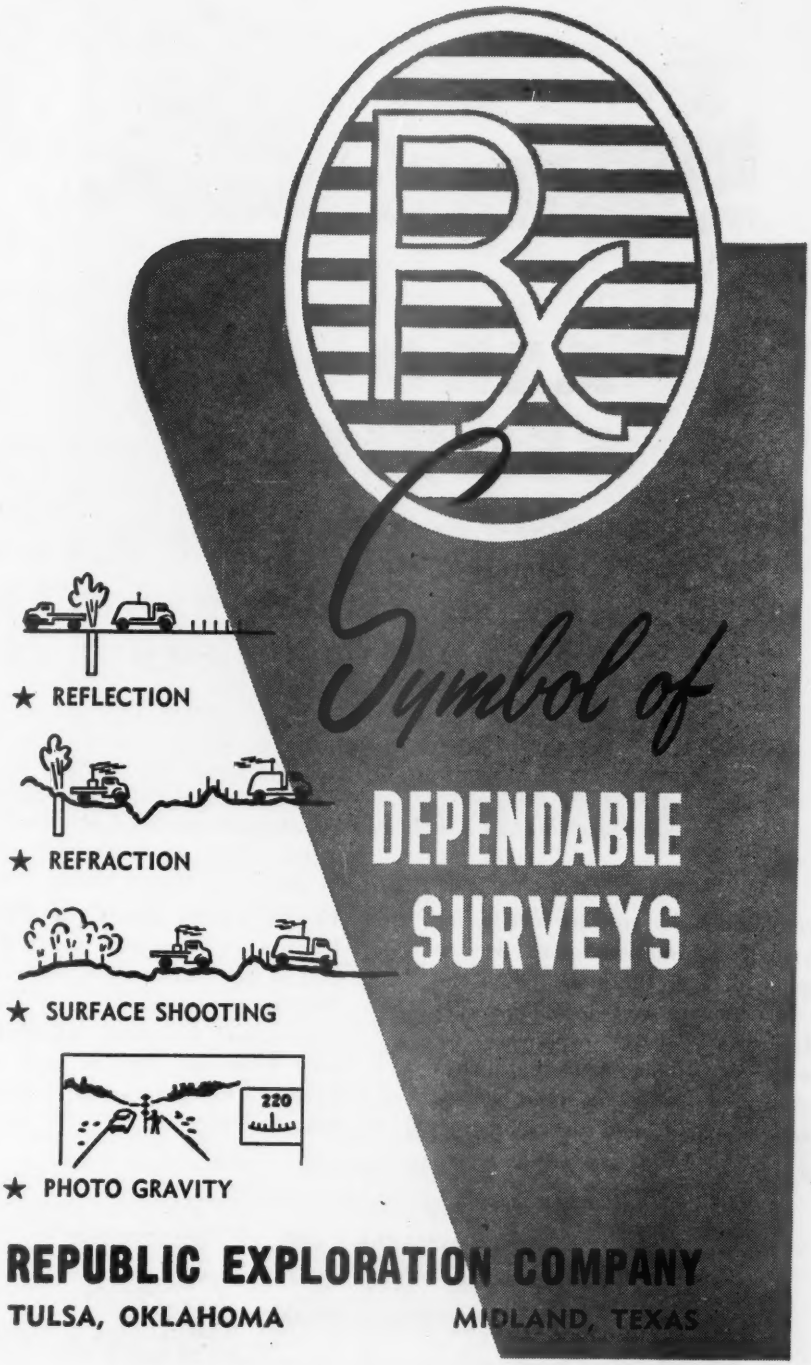
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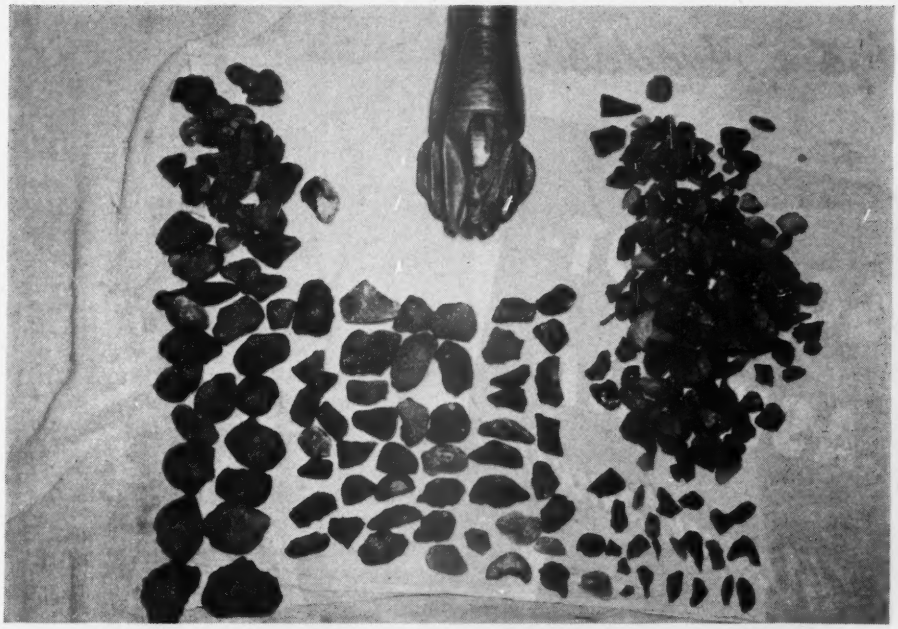

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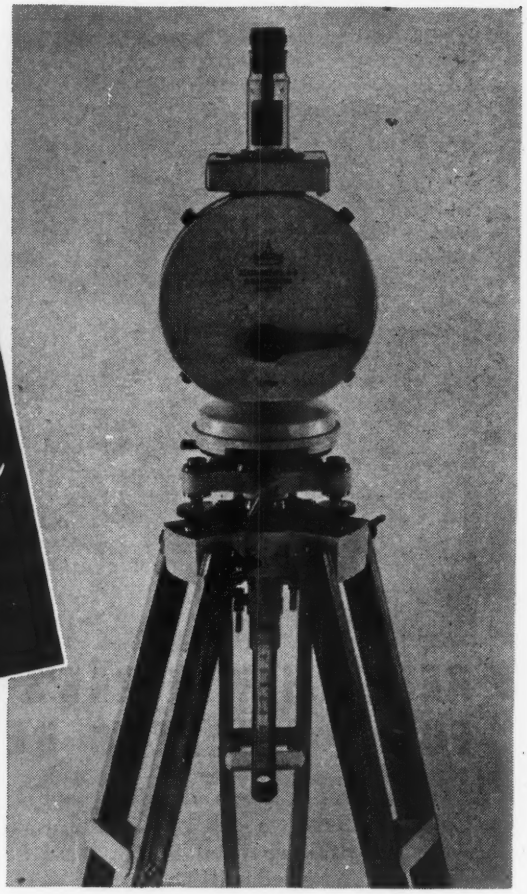

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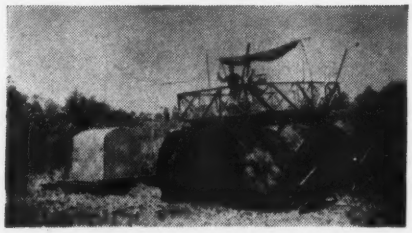

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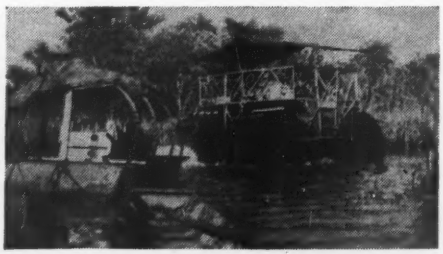

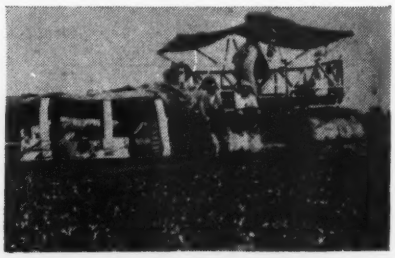

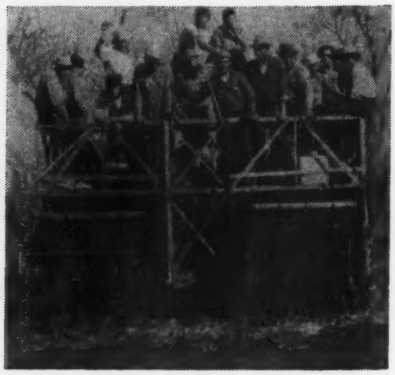

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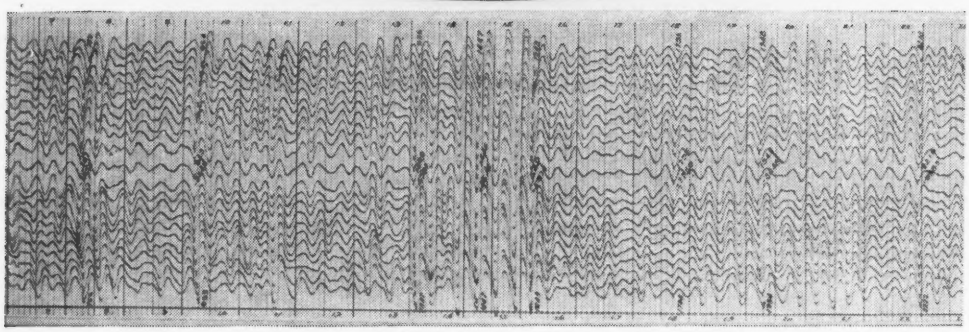

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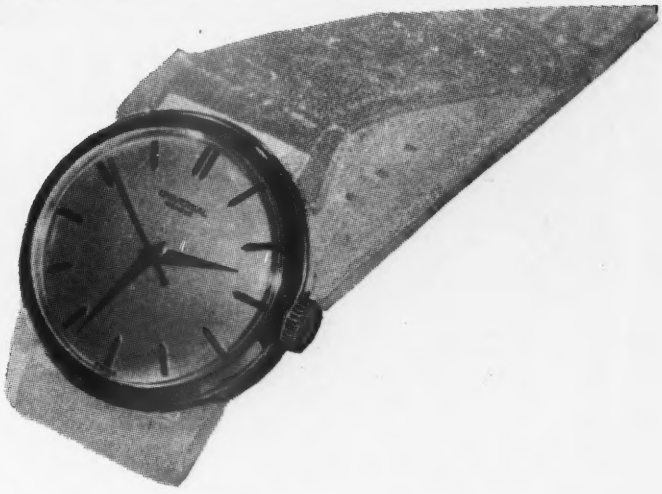

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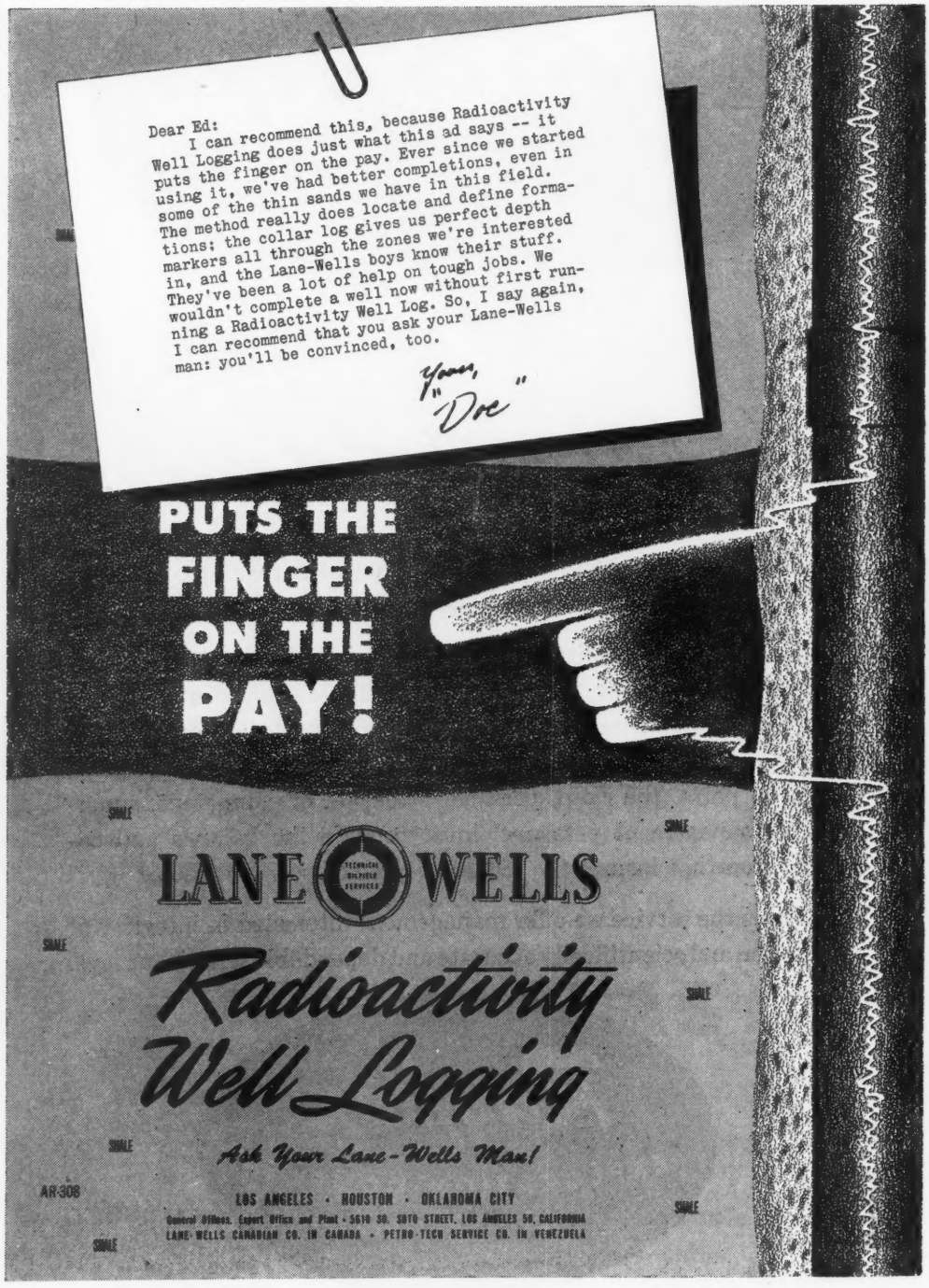
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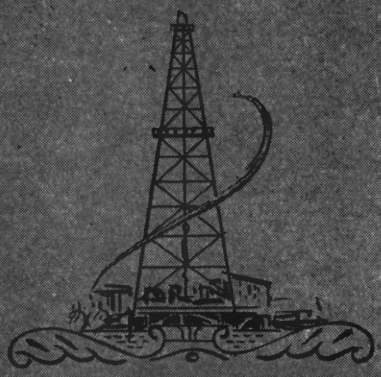

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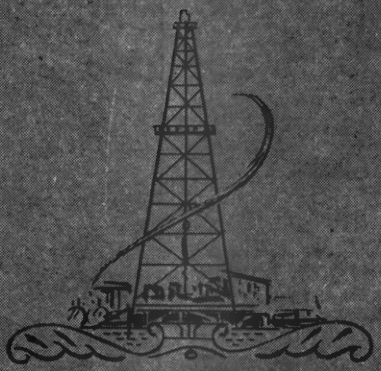

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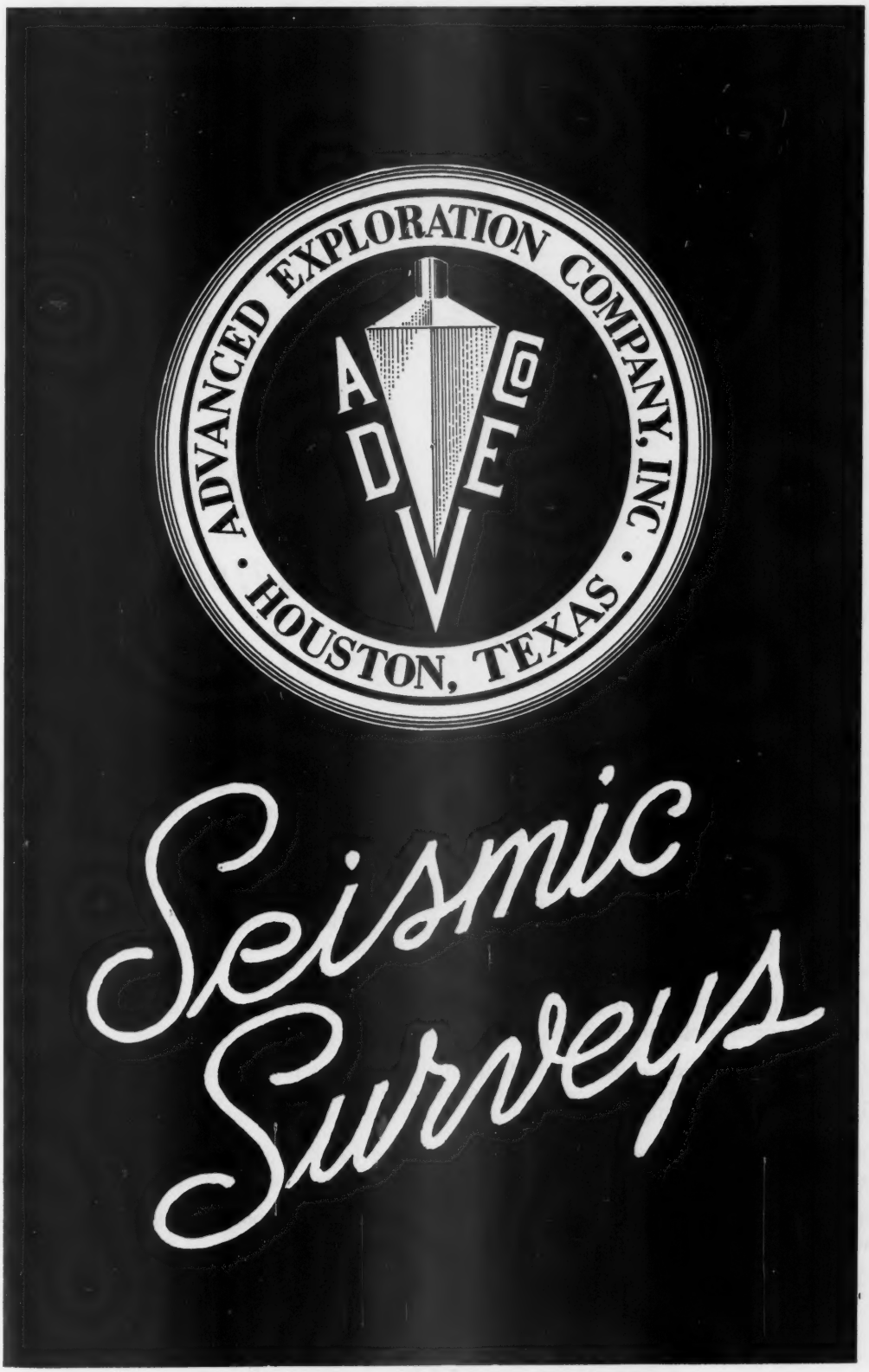
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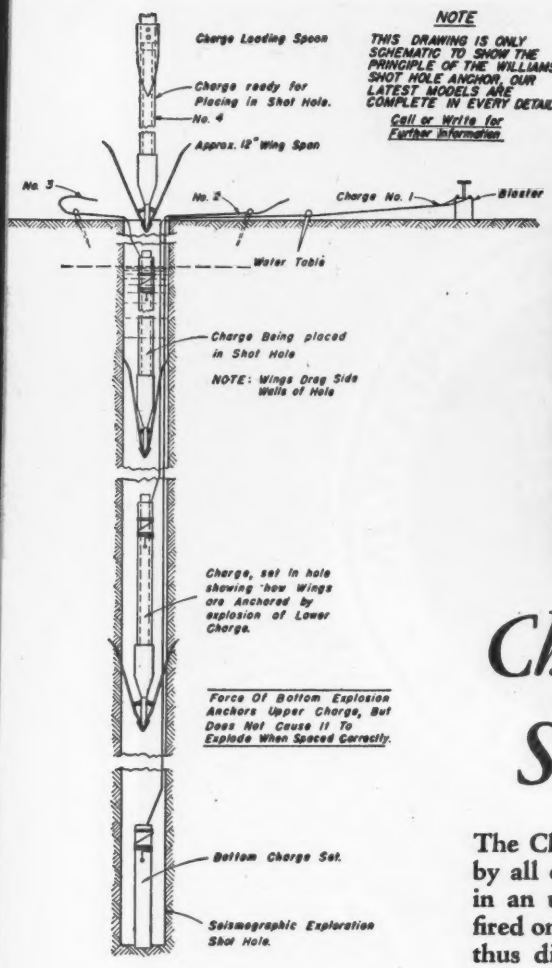
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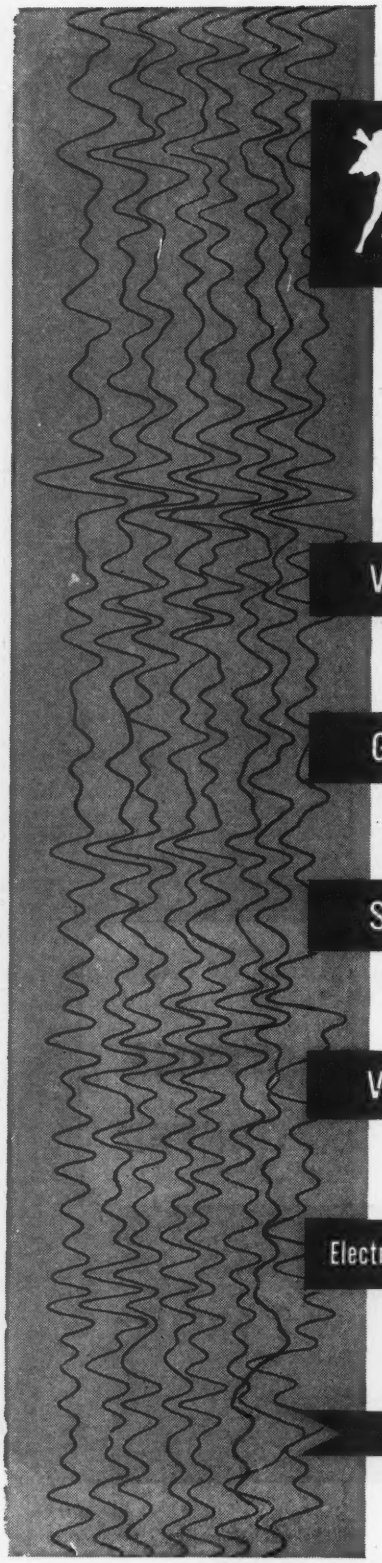

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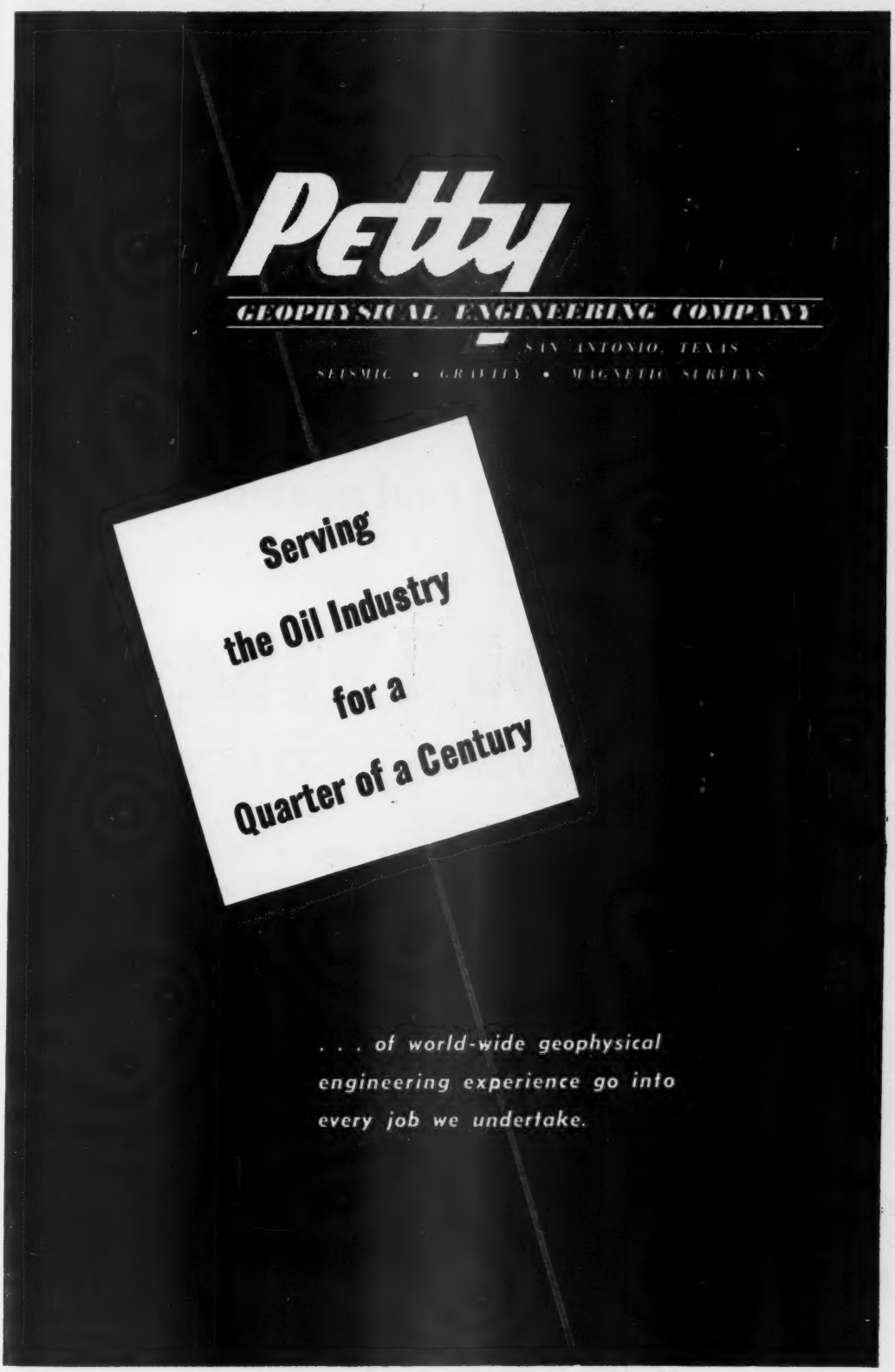
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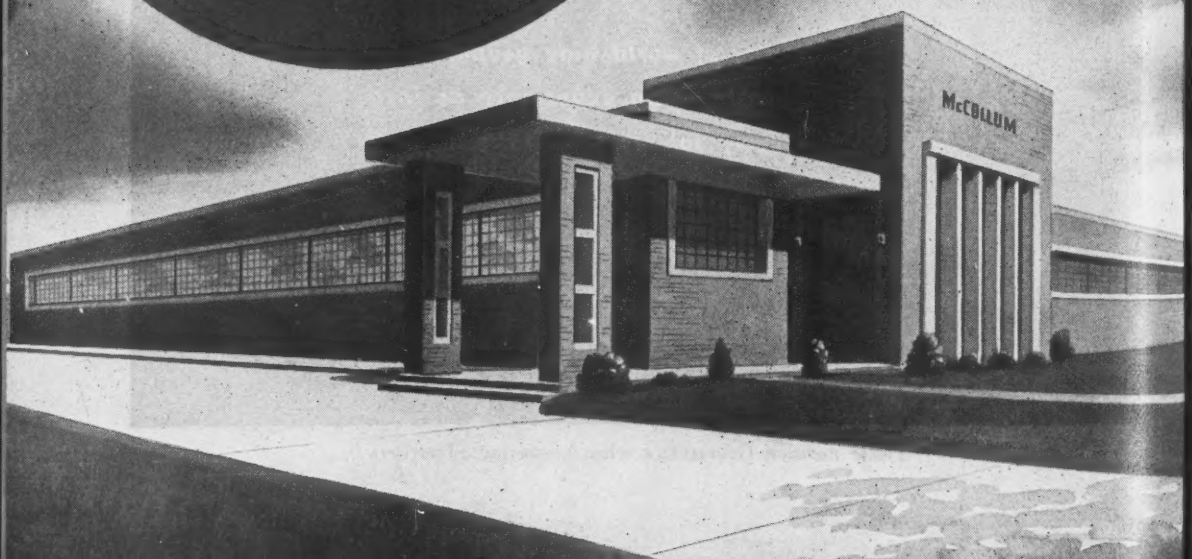

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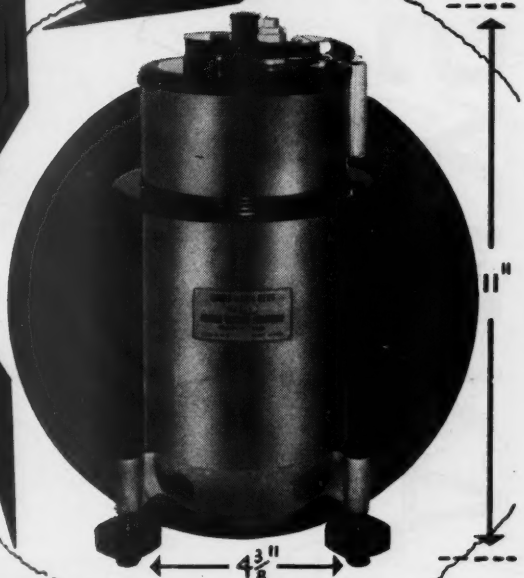

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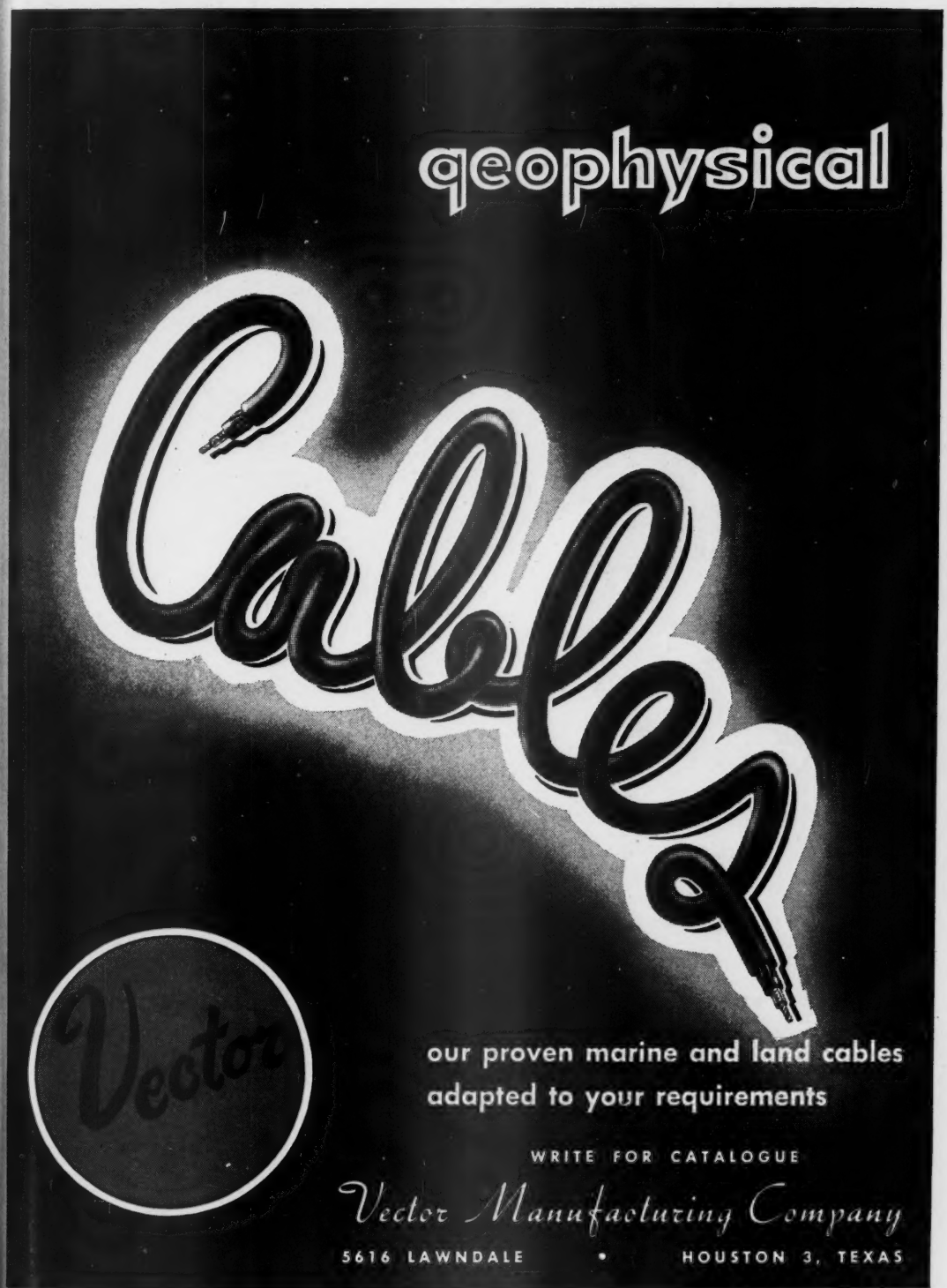
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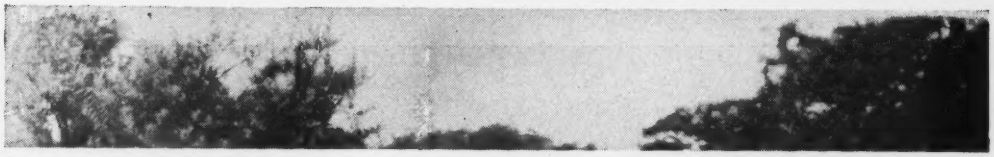

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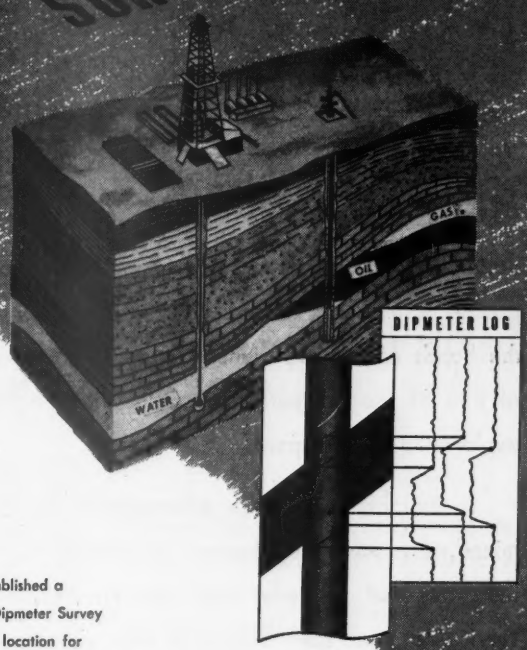

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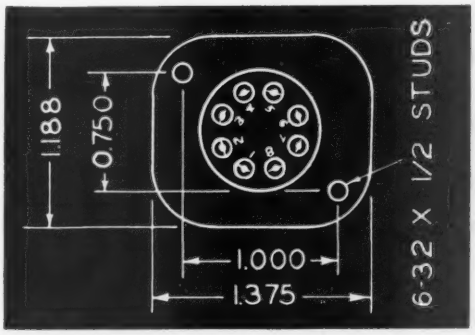

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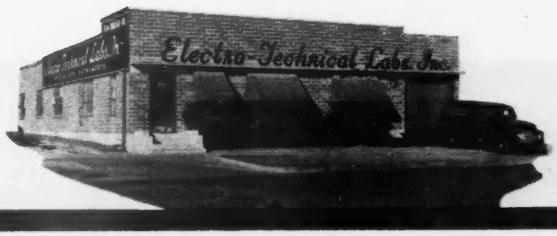

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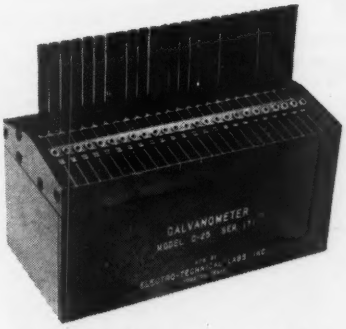

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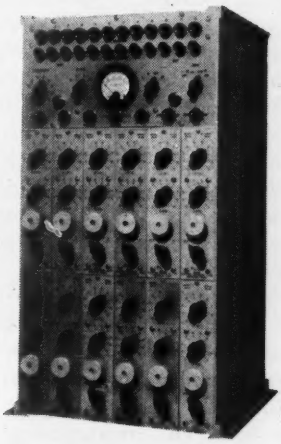
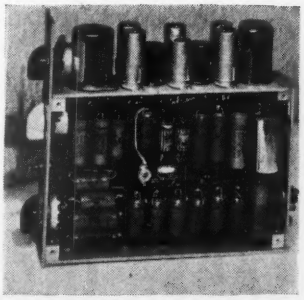
MODEL RA-12 STANDARD AMPLIFIER UNIT

Normally used in Electro Tech's truck mounted installations, this unit is thoroughly proven in field operations. It is, in effect, the forerunner of the M-212 and in general has the same features, including the self-contained control panel—highly efficient.





THE MODEL RA-6 AMPLIFIER used with the Model RA-12 is supplied with either standard band pass (2 or 3 section) or modified band pass filter. The latter has proven especially successful for Gulf Coast and similar operations. Unusual mechanical design of chassis makes service exceedingly simple and helps assure stability by most suitable parts placement.

ELECTRO TECHNICAL LABS., INC.

504 WAUGH DRIVE • HOUSTON, TEXAS • JU-1597

Electro-Tech's TYPE EVS SEISMIC DETECTOR

ACTUAL SIZE

Since it was organized in 1941, Electro Tech has become known for the various models of seismic detectors it has contributed to the industry, each developed to better fill the need. With the increased use of high multiples and difficult portage operations, the type EVS has really come into its own—in fact, nearly 10,000 of these units have been produced and placed in highly successful service, since it was first introduced one year ago. Its popularity is further attested to by the fact that other manufacturers have adapted it for use with their own instruments. Sold in a variety of frequencies and case arrangements, both land and marine, to best suit your needs. (Highly efficient, extremely rugged and economical in total cost and operation, it will pay you to investigate the Type EVS if you have detector needs.)

Technical bulletin on the foregoing and other equipment will be gladly furnished upon request. Our services include engineering and custom building of equipment to your own specifications.

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Are you looking for Reefs?

ABILENE (Texas) AREA REEFS

The above sketch is an idealized conception of the general geologic features.

These reefs are of the pinnacle type with somewhat unusual conditions often existing in the interval between the base of the reef proper and limestone resting on underlying dolomite. The illustration shows a discontinuity in reefing conditions on one side during its growth.

Limes and sands draped over the reef are usually oil bearing. The occurrence of oil in the tip of the reef only may not ultimately apply to all reefs in this area.

Shallow draping and reef presence combine to aid in oil exploration in this general area. That is, a shallow drape structure may lead to reef discovery, or a known reef body may lead to a shallow discovery in the overlying draped beds.

SSC Recommends the Following Approach for Seismic Reef Exploration.

NO. 3 HIGHEST RECORD QUALITY

The sedimentary complications that abut and surround organic reefs usually produce similarly complex seismic reflections. Controlled instrument and shooting tests at the beginning of a survey followed by continual supervisory checks during its progress will determine and maintain the instrumental characteristics and shooting procedure required to record satisfactorily the desired energy. Through this approach, SSC obtains SUPERLATIVE RECORD QUALITY—A MUST for a successful reef exploration program.

(This is one of a series)

Seismograph Service Corporation

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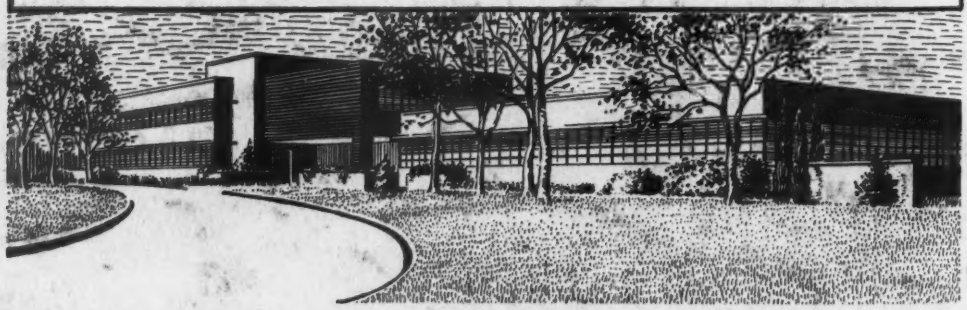
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